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Vol. 209 **MAY, 1930** **No. 5**

CONTENTS

The Autogiro: Its Characteristics and Accomplishments.....HAROLD F. PITCAIRN 571
Some Leading Features of the Stark Effect.....J. STUART FOSTER 585
The Potential Fall between Striæ in Electrical Discharges through Rarefied Hydrogen. JOHN ZELENY 625
Effect of Grain Size in Photographic Emulsions on the Failure of the Reciprocity Law and a Theory of Its Origin.....A. P. H. TRIVELLI AND R. P. LOVELAND 639
Dynamical Analysis of Machines, Part II—Dynamics of Mechanisms..R. EKSERGIAN 649
Committee on Science and the Arts—Abstracts of Reports..... 669
Notes from the U. S. Bureau of Standards..... 679
The Franklin Institute Notes:
Stated Meeting..... 697
Committee on Science and the Arts..... 697
Membership Notes..... 698
Library Notes..... 699
Book Reviews..... 701
Publications Received..... 712
Current Topics..... 668, 678, 714

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INDEX TO ADVERTISERS

PAGE

Ajax Electrothermic Corporation Second cover page

American Platinum Works ii

Arguto Oilless Bearing Co. Fourth cover page

American Telephone and Telegraph Co.....Third cover page

Baldwin Locomotive Works Fourth cover page

Bilgram Machine Works, The.. iv

Borden, John, & Bro..... iv

Cambridge University Press..... vii

Commercial Photo Engrav. Co.. ii

Drexel Evening Diploma School Fourth cover page

Electric Storage Battery Co..... v

Electrical Testing Laboratories.. iv

Fidelity-Philadelphia Trust Co... iii

FRANKLIN INSTITUTE, Awards of x

FRANKLIN INSTITUTE, Award of John Price Wetherill vi

FRANKLIN INSTITUTE, Membership, Terms and Privileges.... xi

PAGE

FRANKLIN INSTITUTE, Pamphlet Reprints of Lectures and Other Contributions v

Girard Trust Co...Second cover page

Glynn Kohler Printing Co..... v

Groschupf & Fehr..... iv

Index (1826 to 1925) Journal of The Franklin Institute.... vii

Lancaster Press, Inc..... ix

Link-Belt Co..... viii

Lonergan, J. E., Co., Oilers, etc., Philadelphia iv

McGraw-Hill Book Co., Inc..... ix

Newbold's, W. H., Son & Co.... v

Philadelphia Electric Co..... ii

Riehlé Bros. Testing Machine Co. iv

Sadtler, Samuel P., and Son, Inc. iv

Smith, Haseltine, & Co., Inc. ... iv

Wetherill, Dr..... iv

White Engineering Corporation, The J. G..... iv

Wood, Alan, Iron & Steel Co. Second cover page

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 209 MAY, 1930 No. 5

THE AUTOGIRO: ITS CHARACTERISTICS AND ACCOMPLISHMENTS *

BY

HAROLD F. PITCAIRN,

President, Pitcairn-Cierva Autogiro Company of America.

MR. PRESIDENT, GENTLEMEN: It is a pleasure indeed to address the members of the Franklin Institute.

To reach a correct understanding of the Autogiro and the principles which underly its performance, I feel that it will first be necessary to tell something of the man who has invented the most remarkable aircraft known up to this time.

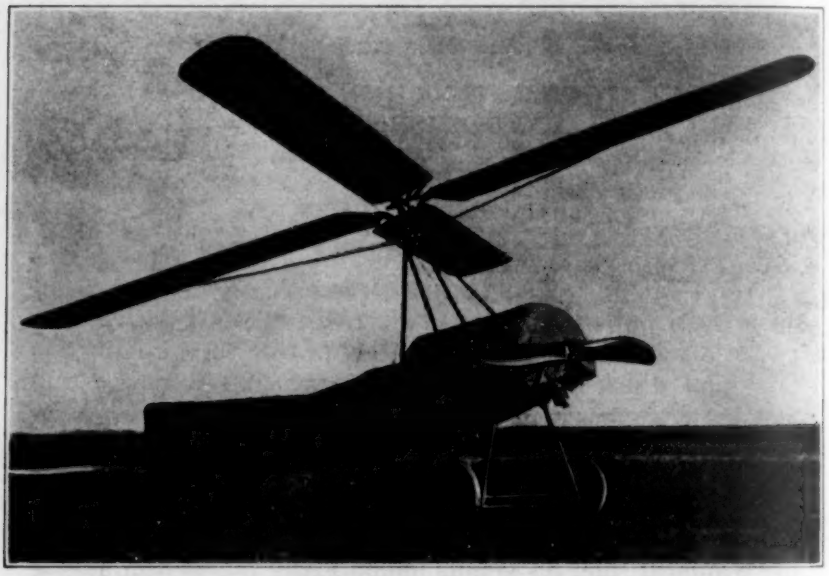
Senor Juan de la Cierva is a Spanish gentleman of great personal charm and brilliance. In his own land he is a person of real consequence, and holds the friendship of his King. On the technical side, his genius undoubtedly places him among the world's foremost mathematicians.

His democratic manner, kindliness and tirelessness in his work have brought him the respect of all with whom he has come into contact, and although he has received some of the highest of the world's honors, he is among the plainest of men in his ways. He is a tremendous worker; the present degree of perfection to which he has attained in the Autogiro is due, almost in entirety, to his efforts alone. He had faith in the principle which he first brought forth, and in the face of many disappointments, due to machines which refused to leave the

* Presented at the Stated Meeting of the Institute held Wednesday, November 20, 1929.

ground, he persevered in his efforts until the Autogiro has finally proven practical and safe.

In his boyhood, Cierva, with two friends of his own age, built and flew kites and gliders. Progressing further, they built, or rather rebuilt, a power plane which flew more successfully than when new. In 1912 a French pilot brought a French biplane to Madrid for exhibition flights. People then were not as accustomed to airplanes as they are now, and when



Earliest practical Autogiro—1923, embodying articulated rotor. Flown at first without fixed wings or ailerons.

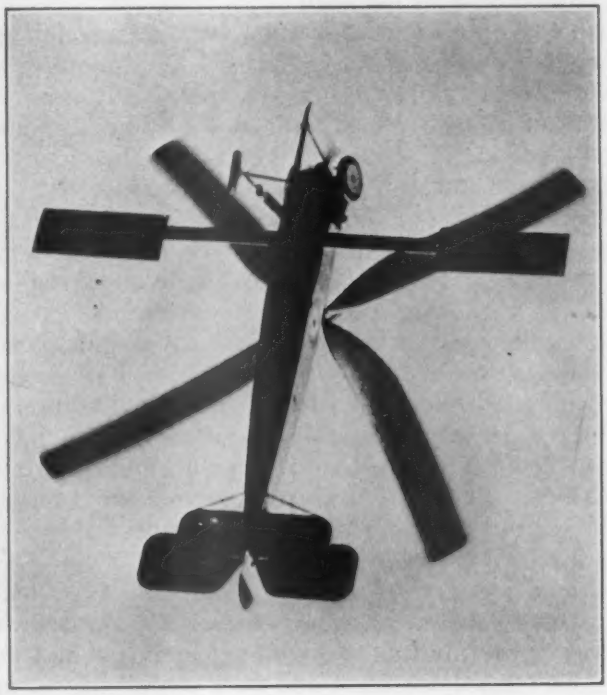
this pilot landed the crowd rushed in upon him, with the result that there was a serious accident. The machine was completely wrecked, although the pilot himself was unhurt.

Later, Cierva and his young friends approached the pilot with the novel offer that they would rebuild the plane if he would test fly it. Thinking it more a joke than anything else, the pilot accepted. There was practically nothing salvageable about the machine excepting the motor and the wheels. With these as a basis, the boys set energetically to work.

The carpentry shop of one of their fathers was open to them

and, doing all the intricate work of fitting bits of wood and stretching canvas, they turned out a machine which flew decidedly better than the original. This machine was the first in Spain.

Later on, in 1913, they started to build a racing plane. In this they had at first the support of their people, who were



The "Devil's Darning Needle" 1925. Armstrong-Siddeley Lynx motor.

encouraged to help them because of their initial success. However, in striving after speed, the boys gave their monoplane so little surface that it could scarcely get off the ground. After several minor taxiing accidents in which undercarriages gave way, their parents' confidence waned and the boys were compelled to give up the project.

All this amateur experimentation had given Cierva the feel

of the air and the conviction that his future career lay in aeronautics. Upon his return to school at that time, which was about at the beginning of the World War, he elected to take an eight years' course covering civil and mechanical engineering, since that was the nearest approach to an aerodynamic engineering course available. At that time there were no schools of aerodynamics in Spain. During his school career he always stood well near the head of his class.

I wish to emphasize that it was Cierva's thorough grounding in engineering and mathematics which enabled him to work out in theory alone the invention of the Autogiro. It was the result of tireless effort and endless patience, and was achieved along logical, constructive lines. The invention was not a haphazard one.

Toward the close of the World War, the Spanish government announced a competition for the design of three types of military planes. These were pursuit, reconnaisance, and bomber. In a sporting spirit, Cierva entered the design competition for the bomber, and produced a plane which in many respects was years ahead of its time. When he designed it, the warring countries still withheld all information on design, so that the machine could truly be called his own. It was a three-motored tractor biplane, with a wing span of around one hundred feet. At that time there were no other three-engined machines excepting the Caproni, and that was not of the modern tractor type.

The machine proved entirely successful. Cierva's test pilot, distinctly scared by its great size, treated it with great gentleness at first, but as he found it responsive and manœuverable, his fears diminished and over-confidence set in, with the result that he flew it in a way that no big machine could be handled, and, while flying near the ground, stalled and crashed. He was only bruised, but the machine was demolished.

The accident caused Cierva to review the entire progress of mechanical flight. He reasoned that if a proven, efficient airplane could be crashed so easily by a seasoned pilot's flying it slowly near the ground, there was something fundamentally wrong with the airplane. He canvassed the entire field of flight by heavier-than-air craft in the search for a fundamen-

tally safe flying machine. Finally, after continuous research in theory and practice, he struck upon the idea of autogiration.

While there are many forms of autogiration, but one seemed practical to the great inventor. This was the result of extraordinarily sound and inspired engineering developed from higher mathematics. The Autogiro would have been impossible without the preliminary development of the correct theory.

English Avro Autogiro (Wolseley Viper Engine), 1927.

On his first machine he used two four-blade rotors. One of these was placed above the other, with the two rotating in opposite directions. He had realized that the lift on the blades while traveling with the flight path would be much greater than while going against it, and the idea of the two rotors with opposite directional rotation was calculated to cancel out the tendency to tip over. He found that the upper rotor turned much the faster, however, and the tendency to tip over was so strong that no real attempt was made to take

it off the ground. This was Cierva's only attempt to use two rotors on the same machine.

His confidence was undiminished, and he set to work on the second type. It should be mentioned here that, although probably in excess of fifty or sixty Autogiros have been constructed, there have been only six or eight general types, and that many models were simply slight modifications of their predecessors. The rotor of the second type employed three rigid cantilever blades. He attempted to compensate for the difference in lift between the blades while advancing and while receding by a mechanism which changed the angle of incidence of each as it revolved, giving the greater angle on the receding blade. This mechanism proved cumbersome and substantially ineffective.

On the third general type, which like the others was constructed around an airplane fuselage, he used five blades, and —it flew. The tendency to tip over was corrected with ailerons. Although it flew but a few feet, he told me that no other machine has ever given him the thrill that he experienced when this proved that an Autogiro could be flown. The machine of course had many deficiencies, chief among which was that of the strong gyroscopic force set up by the rotation of the large rigid rotor. The gyroscopic force was so strong that the controls of the machine had to be greatly modified.

Encouraged by its flight success, however, he built a model which embodied one of the main principles essential to a successful Autogiro. In this he constructed the spars of the blades with rattan, which in itself is quite flexible. This flexibility took the place of the articulation which was the secret of success in later full-sized machines. Also, in a small model rough action would be unnoticed, since there is a very great difference between observing the performance of model, and actually being in a machine yourself. This model flew remarkably well and encouraged him to proceed with further experiments.

It was the next machine, employing hinged joints at the attachment of the blades to the rotor hub, which proved really successful. The construction permitted the blades to flap upward and downward during rotation, so that each vane

automatically took the correct effective angle of incidence at all times. For the first time, the problem of gyroscopic force, which is a very powerful influence to work against, was nullified.

Besides the immediate and great improvement in the performance of the rotor, this articulation solved a number of other besetting problems. It made autogiration possible at angles of attack where otherwise the rotation of the rotor

English Avro Autogiro (Lynx motor) crossing English channel, 1928.

would discontinue. In wind tunnel tests which Cierva conducted in Spain it was found that the rotor would continue to turn at every angle. This however would not be so if the blades were rigidly attached to the rotor hub.

Secondary articulation, permitting variation of the position of the blades with regard to one another along the circle which they describe, was another important step. This gave smooth action to the rotor, which before was rough. Further success came with the addition of the fixed wing, which improves efficiency in the present state of the art of the Autogiro.

Before that time, Cierva had utilized ailerons on outriggers, as it had been found necessary to have some type of lateral control, although he had flown the machines with neither fixed wings nor ailerons.

Another improvement in efficiency came with the use of the geared motor. The gears in this case refer only to reduction of propeller speed since the rotor depends entirely on the action of the air during flight. A large slow turning propeller

The first Autogiro in America, brought to Philadelphia late in 1928 by Harold F. Pitcairn Wright Whirlwind (J-5) motor, Avro fuselage.

gives much greater efficiency at slow forward speeds than a smaller one turning at engine speed. The geared propeller therefore increases greatly the efficiency of the Autogiro since its best angle of climb is at a much slower forward speed than the airplane.

A step toward making the Autogiro practical is the self-starting tail invented during this past year by Cierva. This is a boxlike biplane structure by which the slipstream can be diverted upward while the machine is at rest on the ground, thus bringing the rotor to the necessary speed for take-off. Before the introduction of this feature, it had been necessary to taxi slowly for some time about the field until this rotational speed was attained.

The Autogiro presents certain new problems with the undercarriage because of its ability to land vertically. Although the vertical speed of descent in late models has been as low as twelve feet per second, the condition of landing straight down requires longer travel of the undercarriage with more shock absorption than in the airplane. A satisfactory arrangement is an oleo-pneumatic strut of very long travel combined with the Goodyear air wheel.

The first Autogiro in America, brought to Philadelphia late in 1928 by Harold F. Pitcairn. Wright Whirlwind (J-5) motor, Avro fuselage, flying over Bryn Athyn, Pa.

The stability of any flying machine is a matter of importance. At slow speeds and particularly during vertical descent the Autogiro is inherently and perfectly stable. This is because the center of gravity is well below the rotor. The center of gravity is also slightly ahead of the center of support. This provides longitudinal control during vertical descent and gives the machine a marked tendency to glide forward when the power is cut off. This insures directional control and stability. Very slight forward speed is required for lateral

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control and in vertical descent stability is so great that no control is necessary even in rough weather. In fast forward speed control and stability are similar to the airplane.

In point of performance, the Autogiro offers some distinctly novel experiences to the pilot accustomed to fixed-wing craft. There is something fairly exciting about doing things which he has been instructed to avoid at peril of accident. Such, for instance, as stopping in the air, descending vertically, or even flying backward.

The third Autogiro built in America by Pitcairn Aircraft, Inc., October, 1929. Duralumin tubing fuselage, Wright J-6 225 horse power motor. Air wheel under carriage.

When stopping or descending vertically the sensation, for an airplane pilot, is uncanny to say the least. He has been taught since his earliest flying days not to lose his flying speed, but in the Autogiro this results in nothing more than slow vertical descent. And then if there is some wind and the machine is facing against it, the pilot will have the outrageous sensation of flying backwards in relation to the earth.

Slow speed flying at low altitude is a most pleasant diversion, but it is a sport attended in the airplane with great danger. In the Autogiro, on the other hand, one can fly low and slowly at will, observing at leisure the interesting features of the country. On account of the slow speed he is able

to turn to one side or the other very quickly to avoid objects looming in his path; so in thick weather he can grope his way along at lower altitude than the airplane and also, on account of his slow speed, has time to see obstacles before hitting them. If the engine stops he can get down into very small spaces.

Improvement in the Autogiro must be in the nature of evolution, much as it came about in the airplane. To take a good example, our first Mailwing plane, built about three

Sport Autogiro brought to America August, 1929, by the inventor, Juan de la Cierva. This machine has been demonstrated at Philadelphia and the Cleveland National Air Races by Mr. Pitcairn and Mr. Cierva.

years ago, had a high speed of around 125 miles per hour with 225 h.p. Constant refinement has increased this to 145 miles per hour. With N.A.C.A. cowling this has been further increased to 160 miles per hour, yet with the same horsepower. We expect the Autogiro we have just finished to do about 120 m.p.h. with the 225 h.p., only five miles less than the first Mailwing, and if we compare this machine with the first Mailwing it will be readily apparent that there is much more opportunity for reducing drag in the Autogiro than in the case of the early Mailwing.

The Autogiro is much more susceptible and sensitive to

improvement than is the airplane, and responds in greater degree. For instance, when we recently completed one of the first American machines, its initial flight test showed a high speed of 87 miles per hour. When the pilot landed and reported the disappointing 87-miles-per-hour speed, there were long faces to be seen everywhere.

LePere four-place, cabin, all duralumin Autogiro built in France and brought to this country in September, 1929. American Wright Whirlwind motor, geared.

Senor Cierva held his peace, but when he went to work on his figures that day he checked up everything and told me that 87 miles per hour was correct because of the detail arrangements; and that we would make a few changes in the machine and it would do 105. After these changes were made the next day, the machine did 105, much, I believe, to the surprise of the pilots and aeronautical experts who were present. Later, with other modifications, it definitely is expected to show around 120.

The Autogiro has many more parameters than the airplane. In their sum total and in their relationships to each other and to other combinations, they present an almost infinite variety of viewpoints, by means of which, through evolution and selection, engineers can improve the Autogiro. For instance, in the airplane we have wing area. In the Autogiro we have

blade area, disc area, fixed wing area and the relation of the various areas. In the airplane we have aspect ratio, or the relation of wing span to chord. In the Autogiro we have solidity, or the relation of blade area to disc area. In the airplane we have the wing curve, while in the Autogiro we have the curve of the fixed wing, curve of the rotor blades, and its constantly changing effective curve, caused by its differing attack as it rotates. In the airplane, we have angle of incidence. In the Autogiro, we have the speed with which the air strikes the rotor blades, which is constantly changing on account of the relation between forward and rotational speed. Then, of course, there is the all-important matter of good proportion of the above items. Small improvements to parasitic drag, power loading and disc loading result in relatively large advances in performances.

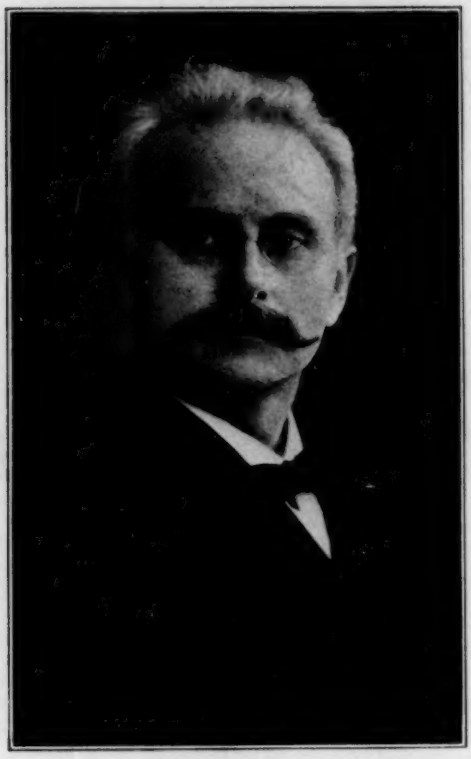
If an airplane, by streamlining or refining some of its parts, increases its speed, say, 10 miles per hour the same degree of refining will increase the Autogiro's speed about 15 miles per hour.

Finally, we are very fortunate in that, unlike the airplane, improvement to one phase of the Autogiro's performance helps the other phases. For instance, modifying the rotor for higher forward speed may be so handled as to decrease rate of vertical descent.

Without the theory worked out and developed by Cierva, all this would be impossible. Recently he has put this theory into written form for the use of engineers. He has also developed a series of graphs with accompanying explanation which will enable the engineer to calculate performance and design Autogiros of various sizes and types. This theoretical work alone would in itself be a monumental achievement for many a lesser engineer.

So far, as I have said, the Autogiro is the work of one man only. Think what the Autogiro will be when the same effort is put on it that has been applied to the airplane. Also, the engineers now concentrating upon the Autogiro have many more factors with which to deal than those who took the airplane in hand, and they have extensive knowledge of aerodynamics to work with, gained from wind tunnel tests and airplane experience.

In conclusion, I may say that the Autogiro is now a practical machine, and within a reasonable time many will be produced commercially. The Autogiro is free from many of the inherent limitations of the fixed-wing aircraft, and while its performance is even now superior to the airplane in many respects, all considerations of performance are subordinated to the one feature which it affords in large measure; that feature is safety.



Stark.

Professor Johannes Stark, discoverer of the effect which bears his name. He was awarded the Nobel Prize for Physics in 1919.

SOME LEADING FEATURES OF THE STARK EFFECT.*

BY

J. STUART FOSTER, Ph.D., F.R.S.C.

Associate Professor of Physics, McGill University.

OUTLINE.

I. INTRODUCTION.

1. Spectra sensitive to physical conditions.
2. Doppler effect.
3. Zeeman effect.
4. Discovery of the Stark effect.
5. The Lo Surdo Method.
6. The general features of the Stark effect (with demonstration)
7. Stark effect essentially a quantum phenomenon.
8. Difficulties in the case of hydrogen.
9. Effects in some complex spectra more typical.
10. Role of the Stark effect.

II. EXPERIMENTAL.

1. The sources of light.
2. Flexibility of the Lo Surdo source.
3. Lo Surdo source as modified by Nyquist.
4. As modified by Foster.
5. High potential apparatus.
6. Operation of source.
7. McGill glass spectrograph.
8. Stigmatic grating spectrograph.

III. ELEMENTARY INTERPRETATION OF H AND HE SPECTRA.

1. Hydrogen atomic spectrum.
2. Sub-levels.
3. Par- and ortho-helium systems.
4. The normal helium spectrum.
5. New combination lines.
6. Fine structure of orthohelium lines.

IV. THE STARK EFFECT IN PARHELIUM.

1. Variations in Stark displacements.
2. Bohr's relation between Stark displacements and "hydrogep differences."
3. Predictions of Stark displacements in known spectra.

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* Presented Thursday evening April 14, 1929.

4. Limitations of early theory.
5. Displacements of diffuse and combination lines.
6. A method of identifying certain combination lines.
7. General behaviour of the new series in electric fields.
8. Dispersion theory applied by Pauli.
9. Patterns of the Stark effect (Analogue of Preston's rule).
10. Incomplete patterns.
11. Quantum mechanics applied to Stark effect in helium.
12. Vanishing components.
13. Crossing of components.

V. COMPARISON OF NORMAL STARK AND ZEEMAN EFFECTS.
1. New lines.
2. Number of sub-levels.
3. Displacements of the sub-levels.
4. Variety of Stark patterns.

VI. STARK EFFECT IN ORTHOHELIUM.
1. The new feature.

VII. STARK EFFECT IN OTHER COMPLEX SPECTRA.
1. Patterns largely determined by quantum number k.
2. Parhelium patterns not universal.
3. Patterns determined by j values.
4. Hydrogen intensities.

VIII. PASCHEN-BACK ANALOGUE.

IX. EFFECT OF PARALLEL ELECTRIC AND MAGNETIC FIELDS ON THE HELIUM SPECTRUM.
1. Experimental arrangement.
2. Results for parhelium.
3. Additional features in orthohelium.

X. EFFECT OF CROSSED ELECTRIC AND MAGNETIC FIELDS.

I. INTRODUCTION.

1. *Spectra sensitive to physical conditions.*

When light from a suitable source is properly directed through the slit of a spectrograph and is analysed, a number of lines are found on the photographic plate. Each line is an image of the slit, and is produced by light of a definite colour. The colours in the incident light are separated by the dispersive system within the spectrograph, and each line takes its characteristic position in the spectrum of the substance under investigation.

It has been found that the spectrum represents in a very sensitive way not only the constituents of the source but also the physical conditions under which the light is emitted. This is accomplished through modifications in the positions, intensities, and other qualities of the lines. For example, it is not unusual to find that some or all of the lines in a spectrum are slightly changed from their usual characteristic colours, and are therefore displaced from the normal positions in the spectrum. There is great variety in the causes for such displacements and in their magnitudes.

2. *Doppler effect.*

Every colour as observed in starlight is changed slightly toward the red or blue when the star recedes or approaches; since this motion affects the rate at which the light waves are received at the eye or the slit of the spectrograph. It is the common practice to use this small Doppler effect to obtain information regarding the character and motion of celestial bodies.

Plate 1(*a*) is a section of the (absorption) spectrum of the planet Saturn and its rings as obtained by Slipher at the Lowell Observatory. For purposes of comparison, vanadium lines from a stationary source have been placed at the top and bottom of the same plate. The Doppler effect reveals a motion of the planet as a whole toward the earth at the time the photograph was taken. Moreover, the slope of the lines through the central portion is a measure of the speed of rotation of the planet; while the change in this slope which occurs in the rings, confirms Maxwell's theory that the latter do not form a rigid body.

3. *Zeeman effect.*

In certain other cases the change in colour occurs within the source itself, and may be due to the direct action of some external force on the atoms while they emit the light. This is well illustrated by the experiments of Zeeman in which magnetic forces were used. Zeeman placed a discharge tube filled with hydrogen gas between the poles of a strong electromagnet and discovered an actual splitting of the Balmer lines characteristic of this gas. When the source was viewed at

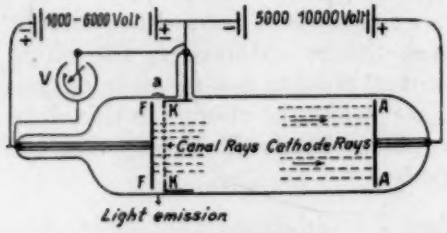
right angles to the applied magnetic field, each original line appeared to be split into three. One of these components was undisplaced and was plane polarized parallel to the field; the other two were circularly polarized perpendicular to the field, and were symmetrically placed with respect to the original line. This type of splitting has been called the normal Zeeman effect. The beautiful illustration in Plate I(*b*) is by Back.

Apart from some very fine features, the Zeeman effect is also nearly normal in the helium spectrum. It is observable in all atomic spectra, and does not vary greatly in magnitude from one element to another, or from one portion of a spectrum to another. While numerous examples of the normal splitting may be found, the effect in general is comparatively complex, (see Plate I(*c*)),[1] and can be explained only on the quantum theory. Wide and important applications have been developed, as for example in the analysis and interpretation of complex spectra.

4. *Discovery of the Stark-effect.*

The Stark effect is so-called after Johannes Stark who discovered this electrical analogue of the Zeeman effect at the Technische Hochschule, Aachen, toward the end of October

FIG. 1.

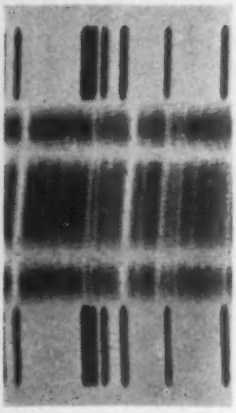


Canal-ray tube (Stark).

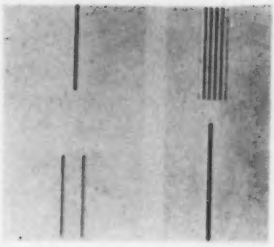
1913. It was produced by the direct application of *electric* forces to the canal rays or positively charged particles (see Fig. 1) which shoot back from a perforated cathode, and (after recovering an electron) serve as the source of light. Under similar conditions Stark obtained, at a later date, the

[1] One of the *D* lines of sodium. The lower image is the normal line; the upper image represents the combined parallel and perpendicular components.

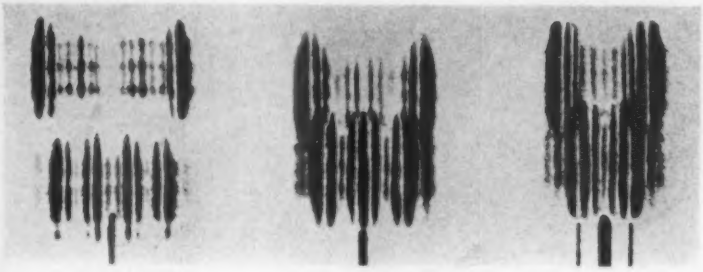
PLATE I.



(*a*) Doppler effect (Slipher).

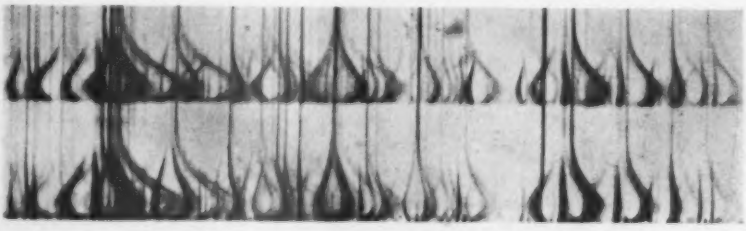


(b) (c)
Zeeman effects (Back).



Hδ Hγ Hβ
(*d*) Stark effect in Balmer series of hydrogen (Stark).

examples of "new" lines Blue Green



(*e*) Stark effect in neon (Foster and Rowles).

beautiful photographs of the Stark effect in hydrogen which are reproduced in Plate 1(*d*). His method has an advantage in that the strength of the field may be found approximately from the potential of the auxiliary electrode relative to the cathode, and the distance between these electrodes.

5. *Lo Surdo Method.*

It was also in 1913 that Lo Surdo made an independent investigation of what was at first appropriately called the

FIG. 2.

Lo Surdo source.

Stark-Lo Surdo effect. He employed a method which has since proved to be much more fruitful. A simple two-electrode discharge tube was used (Fig. 2) in which there was a heavy anode and a relatively small cathode fitted snugly into the smaller section of an ordinary Plücker tube. When a few thousand volts were applied to this tube, the usual fall of potential at the cathode was accentuated, with the result that high electric fields were developed near the cathode surface. The field gradually decreased to zero at the end of the Crookes' dark space a few millimeters distant. It is important to

notice that in this, which is known as the Lo Surdo method, electric forces are not applied artificially to the atoms. Instead they develop automatically as a consequence of the distribution of charges in the source itself. The effect is observable only near the cathode where the lines are gradually split as this field increases. (Plate I(*e*).)

6. *The general features of the Stark effect* (with demonstration).

It is essentially this method which I hope to use in a demonstration of the Stark effect in neon at the end of the lecture. If the experiment is successful you will notice many entirely *new* lines under the action of the electric forces. This characteristic feature of the Stark effect was first reported by J. Koch, who observed it in helium. In further contrast with the Zeeman effect, electric fields produce relatively enormous effects in the spectra of some elements (as neon) and no observable displacements in others. In all spectra where it is observed, the larger displacements are found in lines at the violet end of the spectrum. Plate I(*e*) shows a few neon lines in the blue with displacements somewhat greater than those you may see in the green. The lines which are present in the normal spectrum are displaced toward the red, with very few exceptions; the new lines may be displaced in either direction, and all are found in groups which are somewhat symmetrical in neon and all other spectra showing large Stark effects.

7. *Stark effect essentially a quantum phenomenon.*

Lorentz showed that the assumed classical motion of an electron within an atom is so changed in frequency by an external magnetic field as just to account for the observed modification in certain spectral lines known as the normal Zeeman effect. This classical model failed to provide much stimulus to similar researches with an electric field. In the latter case, the frequency of oscillation remains constant so long as the assumed law of force holds. The oscillations will take place about a new position of equilibrium, but will have the same period as before.

A change does occur, however, in the potential energy of the electron with respect to the external field, through the displacement of its mean position. The discovery of the

Stark effect was therefore welcomed by Bohr as a striking verification of his new expression for the frequency of a spectral line, *viz.*

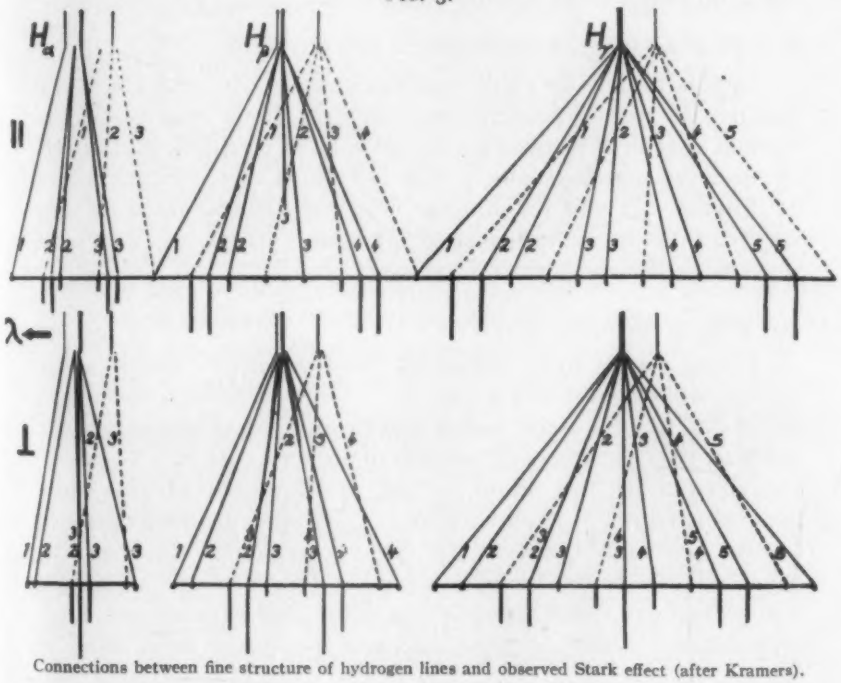
$$\nu = \frac{(E'' - E')}{h},$$

where ν is the frequency, E', E'' the negative atomic energies of the "initial" and "final" stationary states, and h is Planck's constant. This expression has the general form needed to explain the Stark effect, since the frequency of light emitted or absorbed by an atom is made dependent upon an energy relation instead of being coincident with a frequency in an assumed motion. Thus the Stark effect is essentially a quantum phenomenon.

8. *Difficulties in the case of hydrogen.*

All physicists know that neither the experiments nor the more elementary theoretical treatments of the Stark effect in

FIG. 3.



Connections between fine structure of hydrogen lines and observed Stark effect (after Kramers).

hydrogen are quite successful in giving an adequate representation of the phenomenon. Unfortunately, either may leave the erroneous impression that hydrogen lines of single frequency are split symmetrically by the application of a moderate external electric field. A more comprehensive theoretical treatment carried out by Kramers (Fig. 3) on the original Bohr theory, and by Schlapp and Rojansky on the basis of the new mechanics has emphasized the *asymmetry* in the contributions from the *individual members of the fine structure*. This asymmetry in the displacements is retained even after the components have fused in low electric fields to form the Stark components which in theory and experiment are nearly symmetrical for the entire fine structure group considered as a unit. The theoretical superposition of certain Stark components in high fields, as well as the most interesting changes in very low electric fields present great difficulties to the observer. It thus appears that the Stark effect in hydrogen is a comparatively complex phenomenon with a large proportion of its essential features as yet unobserved.

9. *Effects in some complex spectra more typical.*

In this review we shall deal more especially with the main features in non-hydrogen-like spectra. Thus restricted, the subject matter lies more easily within the compass of a single lecture, yet contains much that is typical of the Stark effect in general. It will include the relatively simple data for the spectrum of parhelium, where the observations and the contacts with theory approach completion.

10. *Role of the Stark effect.*

Owing to its later discovery, and especially to its more limited appearance in the spectra of the elements, the Stark effect has played a role much less prominent than that of the Zeeman-effect in the organization of spectra. It has, however, contributed its full share to the development of the more general features of atomic theory. The simultaneous growth of the quantum theory with the experimental data on the Stark effect has led to an interesting fusion of the two. At many stages in the mutual development, the experiments have stimulated further progress in theory or have been used to

indicate the degree of success already attained. In most cases the experimental material has been at hand for these purposes.

Having taken this rapid survey of some of the leading features of the Stark effect, let us now make a more methodical approach to the subject, and consider (i) the production and elementary interpretation of the photographs and (ii) a series of contacts with theory interspersed with the more detailed experimental facts. If the time permits, I shall conclude with a group of photographs indicating the kind of effects one obtains when simultaneous electric and magnetic fields are employed either parallel or crossed at right angles.

In order to speak as definitely as possible about the experimental side of the subject, I shall follow the suggestion of your secretary and draw mainly from our experience at McGill.

II. EXPERIMENTAL.

1. *The sources of light.*

The primary interest lies in the source, where a difficulty appears which is especially prominent in studies of the Stark effect. I refer to a slight unsteadiness in the applied electric forces. Even in a canal-ray tube space charges may give rise to forces which cannot be neglected in comparison with the one intended to be directly applied. In the Lo Surdo tubes, the entire range of electric fields must be attributed to such an origin. These fields will change if the source is at all unsteady. Difficulties of this nature are not treated fully in the literature, though they may be the first ones considered by the investigator who wishes to make a trustworthy analysis. By way of contrast, we notice that the current in a discharge tube cannot produce a *magnetic* field at all comparable with those used in studies of the Zeeman effect. For this reason, the magnetic field usually remains more nearly constant in experiments.

The canal-ray tube (Fig. 1) is run at a comparatively low pressure, the length of the Crookes' dark space being 5 to 10 cms. The distance between the cathode and auxiliary electrode is so small that charged particles fly across without collisions; consequently no regular discharge is sustained in this portion of the tube. At this low pressure the tube is rather steady, but the source is not especially bright. If the tube is forced to give its maximum light, it becomes less steady.

Lo Surdo sources (Fig. 2) are run at various pressures up to about 4 millimeters of mercury. The so-called Crookes' dark space is traversed by a central beam which is very bright. The general appearance is very well represented in (Fig. 4)

FIG. 4.

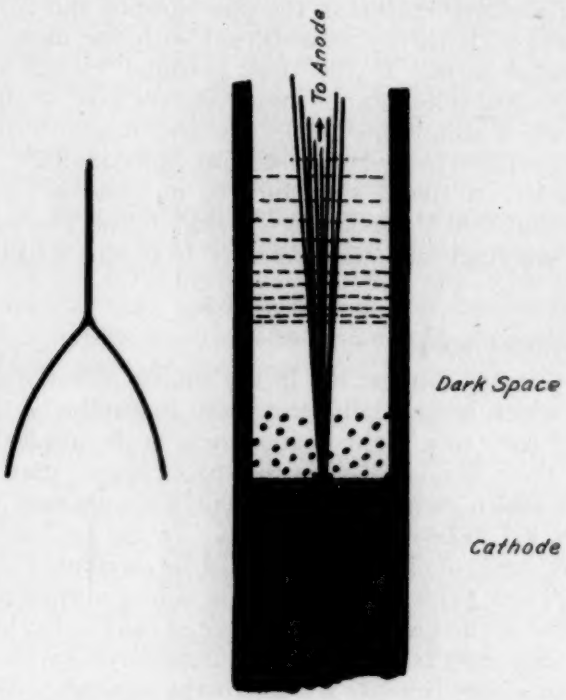


Diagram of Crookes' dark space and splitting of hydrogen lines by electric fields developed there (Lo Surdo).

which has been copied from a sketch by Lo Surdo. As already mentioned, it is here that a range of electric fields is established by the rapid fall of potential.

In the analyses obtained from these relatively bright sources one has the very great advantage of seeing on one plate the effects of the entire range of electric fields, continuously represented.

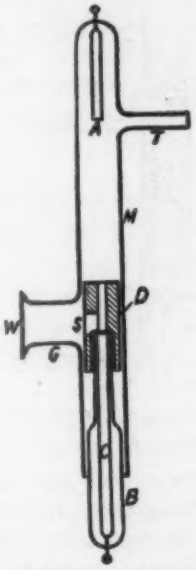
2. *Flexibility of the Lo Surdo source.*

Time does not allow a full description of each useful form of this flexible source, which has been modified to suit the requirements of each individual investigation. Two models are considered in the following sections. Beside these, noteworthy developments have been made by Anderson for a study of the Stark effect in the spectra of metals; by Hansen for an investigation of the Stark effect in mercury, and by Kiuti for the production of very high fields.

3. *Lo Surdo source as modified by Nyquist.*

A serious trouble developed in the original Lo Surdo source owing to cathode sputtering which rapidly coated the adjoining glass wall, and thus reduced the intensity of available light to a very low value.

FIG. 5.



Lo Surdo tube (Nyquist).

Nyquist avoided this by using a larger main tube into which he inserted a hollow aluminium cylinder insulated from the inner cathode by a second glass tube. (See Fig. 5.) A narrow slit in the aluminium cylinder allowed the light to

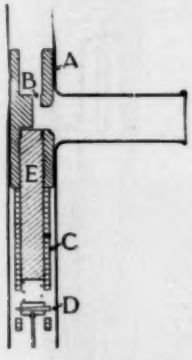
pass out through a side window to the spectrograph. The design prevented harmful sputtering, and in addition made it much easier to keep the tube sufficiently cool.

On the other hand, difficulties developed when an attempt was made to establish high electric fields. The slight discharge between the wall of the main tube and the aluminium cylinder was then increased. This action eventually became irregular, and caused large fluctuations in the applied voltage. The resultant Stark components were more diffuse.

4. *As modified by the author.*

In the tube now used at McGill we have removed this trouble by exchanging the aluminium cylinder for a lavite plug which can be sealed into pyrex glass. No discharge

FIG. 6.



Lo Surdo tube (Foster).

passes between the glass wall and the lavite under any circumstances. The form has other advantages. It permits the use of a heavier cathode which less easily overheats. The hole through which the discharge takes place is bored slightly off centre, in order that the cathode may be rotated to expose different sections of its surface to the severe bombardment of the positive ions. In this way excessive pitting is avoided, and an opportunity is afforded to change the cathode surface if the first section exposed proves to be unsatisfactory for a steady discharge. The plane cathode surface itself is spaced a fraction of a millimeter from the lavite immediately above

it to prevent contact with the sputtered metal which rapidly collects on the latter. By a gradation of the diameter of the hole through which the discharge passes, and proper spacing of the cathode from the lavite, good control over the field distribution in the Crookes' dark space may be obtained. This will be recalled later in the lecture.

The bright light from this region passes through a narrow slit in the lavite. A side tube and window are not essential. In fact they may be troublesome on occasions, since the side tube supplies a normal spectrum which is superimposed on the Stark effect and may mask real Stark components with small displacements.

5. *High Potential Apparatus.*

The source should be excited by a high potential supply which will furnish a few milliamperes of direct current at upwards of 5000 volts. The accompanying photograph represents a portable outfit assembled at McGill from parts manufactured by the General Electric Co., and arranged according to a scheme first described by Hull. This will deliver 100 milliamperes of rectified current at 10,000 volts.

6. *Operation of source.*

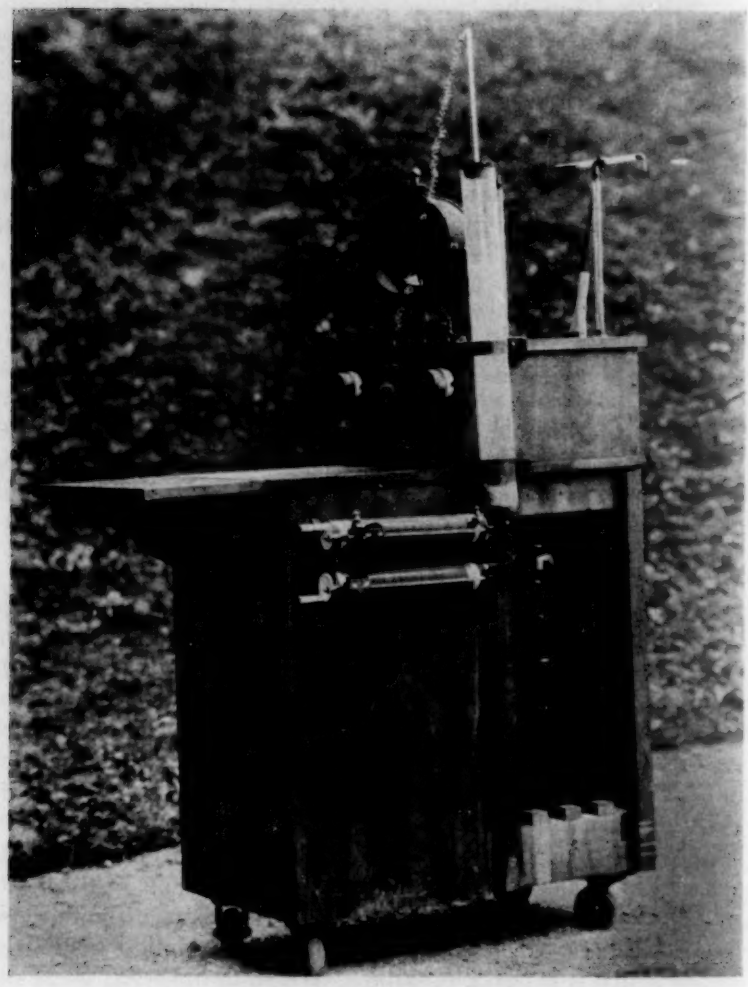
When the tube is first started, it will be too soft for satisfactory operation unless the occluded gases have been thoroughly removed. In any case it should reach a steady state after about fifteen minutes. It is most important to keep the voltage on the tube constant by slight adjustments of the resistance in the primary of the main transformer. Such changes in pressure and current as are then likely to occur are much less harmful to the analysis.

The light, taken from the source immediately above the cathode, is focused on the slit by a suitable lens. A double-image prism is commonly inserted to separate the light in which the electric vector is parallel to the applied field from that in which it is perpendicular. We shall find that there are important differences in the analyses of the two images.

7. *McGill glass spectrograph.*

Since the light intensity is always an important factor, most analyses have been made with prism spectrographs.

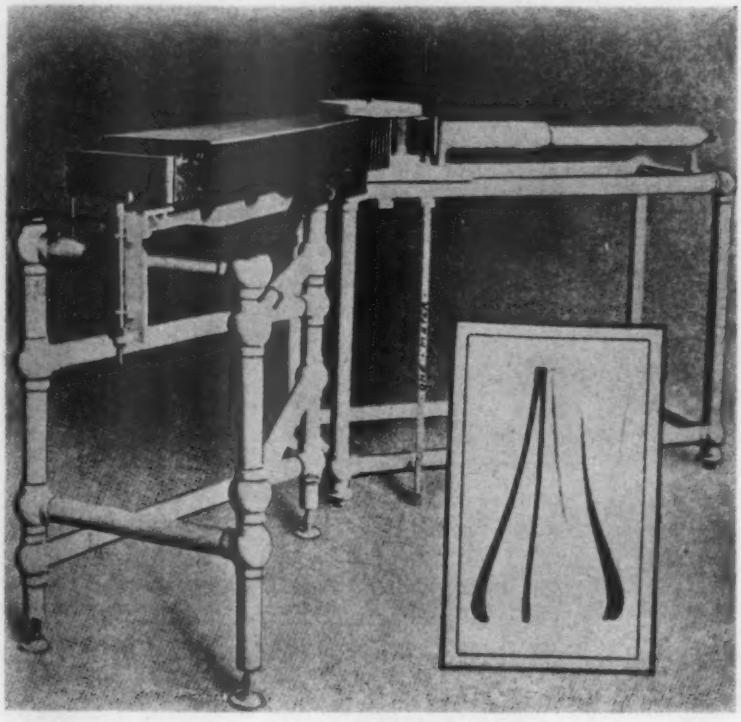
FIG. 7.



High potential apparatus (McGill).

Satisfactory results have been obtained with a six-prism glass instrument (Fig. 8) which I made for this work at Yale. It has since been reproduced at McGill with larger prisms and a few other improvements. The faces of the new prisms are $4'' \times 2\frac{1}{4}''$. They require a good thermostat, which is built into the prism chamber. The collimator and camera lenses

FIG. 8.



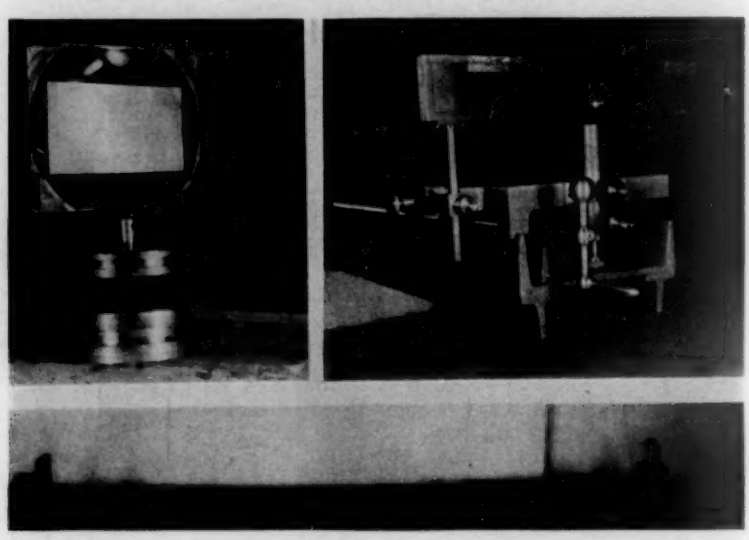
Six-prism glass spectrograph.

are Hastings-MacDowell doublets of 115 cm. focal length and 7.6 cm. aperture. The construction of the prism chamber is such that it may be taken apart and rebuilt with the camera in any position determined by the number of prisms needed for a particular analysis. This spectrograph gives good resolution and bright spectra. The dispersion is from 9 to 2 Angstrom units per millimeter.

8. *Stigmatic grating spectrograph.*

We have recently installed a 30 ft. concave grating at McGill with stigmatic mounting slightly modified from the Wadsworth form as described by Meggers and Burns. The light passes from the slit to a 21 ft. concave mirror (Fig. 9) and returns in a parallel beam to the grating which focuses it on the photographic plate. The mountings are of metal and the instrument is kept in a room with a thermostat. The plate may be changed without entering the room.

FIG. 9.



McGill grating spectrograph. A Wadsworth stigmatic mounting is employed with a 30 foot grating of special character.

The grating which I am now using was ruled in March 1929 by Prof. R. W. Wood and Mr. H. M. O'Bryan. It has 15,000 lines to the inch, and a ruled area 7.5 cm. x 13.5 cm. The central image is very weak, while the first order spectrum on one side has great brilliancy. In this spectrum the grating is fully as fast as the glass spectrograph. The dispersion is 3.8 Angstrom units per mm. Ghosts are strong. Preliminary results indicate that this instrument will be very useful in the analysis of Stark effects and more especially, the effects of combined electric and magnetic fields.

III. ELEMENTARY INTERPRETATION OF H AND He SPECTRA.

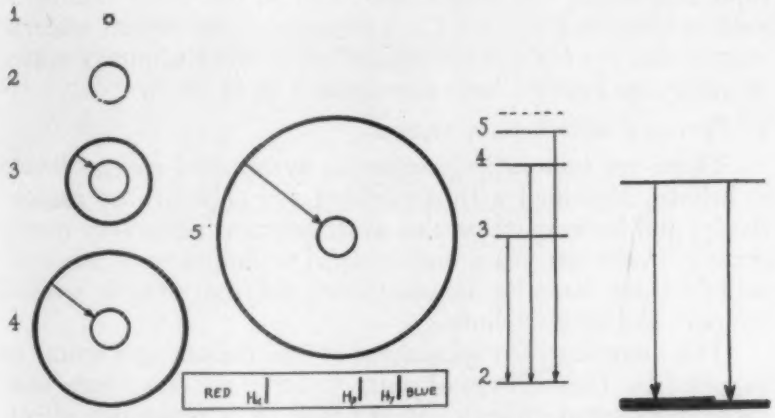
1. *Hydrogen atomic spectrum.*

In the initial Bohr interpretation of this spectrum, "stationary states" are postulated for the atom, and no radiation is emitted unless the atom passes from one such state to another of lower energy. If the change in energy is ΔE then the relation which gives ν, the frequency of emitted light is

$$h\nu = \Delta E,$$

where h is Planck's constant. The experimental results, as presented by Balmer, allowed Bohr to suggest a picture of the

FIG. 10 (*a*). FIG. 10 (*b*).



Normal and excited hydrogen atoms, with transitions which give rise to the hydrogen lines H_α, H_β, H_γ. The latter are shown again in the energy level scheme at the right.

stationary states in which the electron revolves in one or another of a series of circular paths with radii proportional to the squares of successive whole numbers, $n = 1, 2, 3. \ldots$ Some energy levels for the hydrogen atom are shown in Fig. 10(*a*) together with the atomic changes or electron "jumps" which lead to the commonly observed Balmer lines.

2. *Sub-levels.*

It is rather important to recognize that the energy levels are not simple under close examination; but have a fine structure which is very difficult to observe in hydrogen. Without

making any attempt to bring out fine theoretical features, we recall that there is experimental evidence to prove that the second level is double. [Fig. 10(*b*).] The separation of these two sub-levels appears in each Balmer line. Since the remaining fine structure features in hydrogen are not easily observed, we shall pass to the helium spectrum.

Owing to the perturbing influence of the second (inner) electron, we find that here the sub-levels have comparatively wide separations. In fact, it is so great in the case of the second level (Fig. 11) that transitions to the lower level lead to lines in the ultra-violet, while transitions to the upper level gives a series of visible lines which appear in the spectrum very close to the Balmer lines of hydrogen. The third level has three sub-levels, the fourth four, and so on. The number l used to identify a sub-level is a measure of the orbital angular momentum ($= l \cdot h/2\pi$) corresponding to the stationary state. In each case l covers the range from 0 to $(n - 1)$.

3. *Par- and ortho-helium systems.*

There are two entirely separate systems of energy levels in helium, identified with parhelium and orthohelium respectively, and between these two systems transitions very rarely occur. For some years unsuccessful attempts were made to explain these facts by assuming two different atomic models for par- and ortho-helium.

The quantitative explanation of the helium spectrum, as supplied by Heisenberg, appears to have no very close analogue in classical theory. It is based on a resonance effect, characteristic of the quantum theory, in which the two electrons of the helium atom change places at a rate dependent upon the difference between corresponding parhelium and orthohelium energy levels. In addition to a formal demonstration of the origin of the two systems of energy levels, Heisenberg interpreted the fact (observed later) that the orthohelium lines are triple as well as the older observation that the parhelium lines are simple. The diagrams refer to parhelium.

4. *The normal spectrum.*

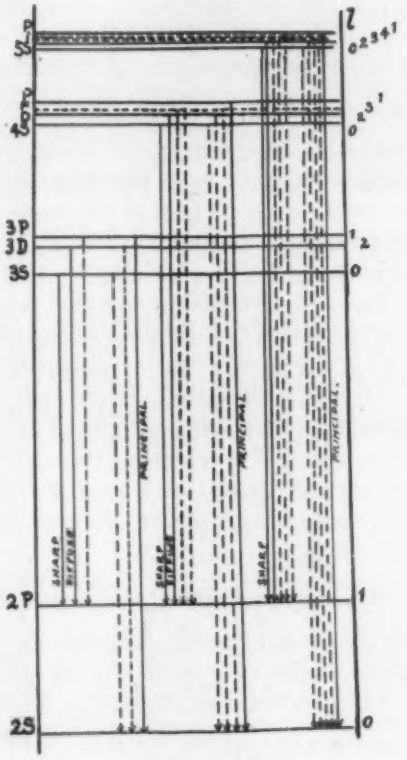
Although the helium sub-levels identified by a series of l values may exist at all times in a light source, we do not

ordinarily get full information about them from observations in the visible or ultra-violet regions. For under normal conditions the transition from one atomic state to another is such that l changes by *one* unit only. In accordance with this "selection rule," the diagram illustrates the origin of the sharp, principal, and diffuse series.

5. *New combination lines.*

As first clearly recognized in the experiments of J. Koch, and well illustrated by Hansen Takamine and Werner (see

FIG. 11.



Energy levels of parhelium. At the right are the l values; at the left, the spectral "terms" which spectroscopists identify with the levels.*

* Hydrogen spectral terms may be expressed in the form R/n^2, where R is Rydberg's constant and n is the principal quantum number. The connection

also Plate 1(*e*)) an outstanding new feature introduced by the electric field in the Stark effect is the production of new lines through a breaking down of the above selection rule. In the presence of an electric field of sufficient strength, Δl may assume all possible values. Returning to our diagram (Fig. 11), we may now "dot in" one new transition here, two there, and so on. In each group of lines there is one line more than in the previous group, corresponding to the increased number of sub-levels. The electric field thus induces the atom to tell a more complete story of its structure. The field which exists between the wires of an ordinary direct current lighting circuit is ample to bring out most of the new colours in helium. The fact that such low fields are sufficient is not usually stated in the literature on this subject.

6. *Fine structure of orthohelium lines.*

In parhelium the electrons spin in opposite directions; hence the angular momentum so introduced is zero. But in orthohelium the two electrons spin in the same direction giving a resultant spin angular momentum $= h/2\pi(\frac{1}{2} + \frac{1}{2})$. We may picture this as added vectorially to the orbital angular momentum to form the resultant $j \cdot h/2\pi$, where j is a whole number. With the vectors oriented in proper directions to form $j = l - s$, l, $l + s$, the atom theoretically assumes a series of energy levels which differ from each other enough to account for the observed triplet structure of the orthohelium lines. Normally, there is a selection rule according to which $\Delta j = \pm 1$ or 0, except that $j = 0$ to $j = 0$ does not occur. This rule, like the rule for Δl, is not effective in the presence of external electric fields.

IV. THE STARK EFFECT IN PARHELIUM.

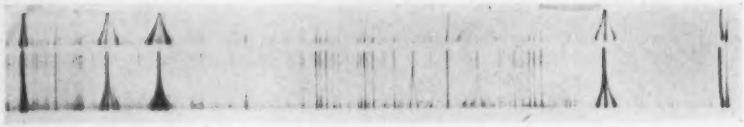
Plate 2 (*a*) gives a general view of the Stark effect in parhelium together with very similar effects in hydrogen and orthohelium. Plate 3 * shows that the effect in parhelium

with the energy levels is seen from the fact that Rhc/n^2 represents the work needed to remove the electron from the influence of the nucleus. Here h is Planck's constant and c the velocity of light. In helium (and other elements) the terms may be represented by $R/(n + \delta)^2$ where δ is small for a *hydrogen-like* term.

* The author wishes to express his thanks to the Royal Society for permission to reproduce Plates 3, 4, 5 and Figs. 3, 6, 12, 17, 19 from the 'Roy. Soc. Proc.'

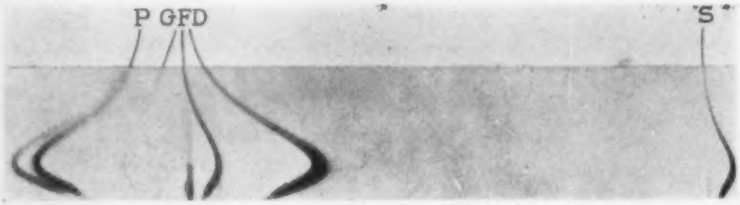
PLATE II.

(a)



General view of the Stark effect in helium. Some of the groups are marked parhelium, orthohelium, or hydrogen.

(b)



Parhelium group λ 4388; π components in electric field or with E parallel to H. Note reappearance of weak component in high fields.

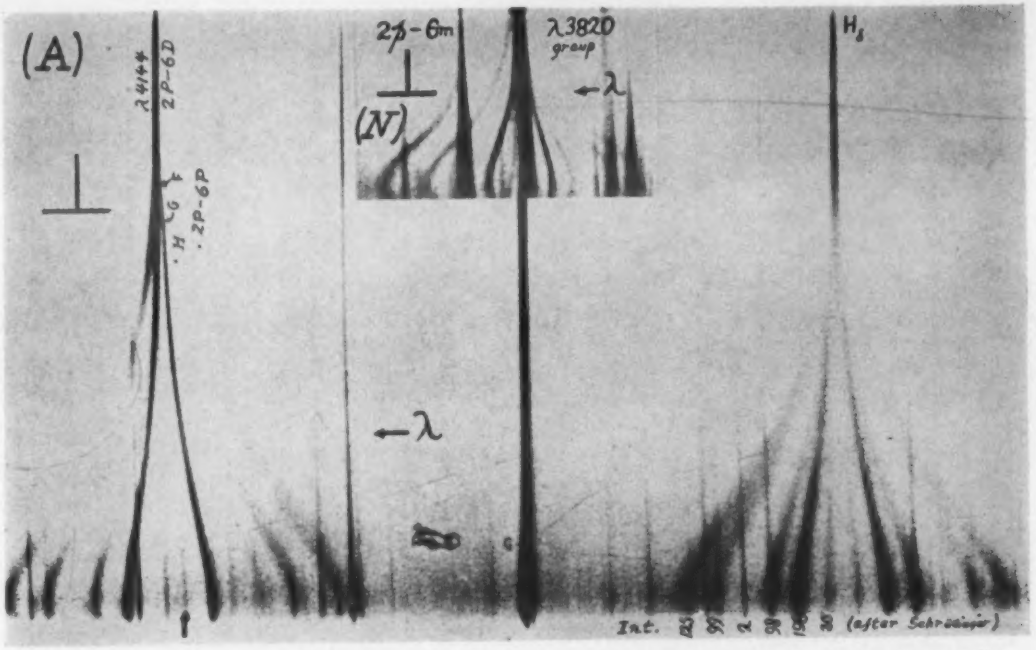
(c)

Same group; σ components in electric field.

(d)

Same group; σ components in parallel fields.

PLATE III.



This group of parhelium lines presents a Stark effect very similar to that which appears to originate in a single hydrogen line.

line groups may even provide an interpretation of the effect in corresponding hydrogen lines (see Kramers later).

We shall now examine the experimental facts with more attention to detail, and consider the explanations of each feature as provided by the quantum theory. The origin of the numerous new combination lines has already been described.

1. *Variations in Stark displacements.* A casual examination of our plate reveals a second feature first observed by Stark, namely, a great variety in the displacements. The diffuse series have almost as great displacements as are found in the neighbouring hydrogen lines, while the members of the sharp and principal series are only slightly affected. In hydrogen the displacements are found proportional to the applied field; but in the sharp and principal series of helium they are smaller and vary as the *square* of the field.

2. *Bohr's relation between Stark displacements and hydrogen differences.* The *small* displacements in the *sharp* and *principal* series of helium have been explained by Bohr. We have seen that a group of parhelium sub-levels corresponds to each principal energy level in the simple hydrogen atom According to the Bohr orbit theory these are associated with orbits for the outer electron which are nearly Keplerian in character except for a small fraction of each revolution of the electron in those orbits in which it approaches very near the nucleus. In each group this approach to the nucleus is nearest for the orbit of greatest eccentricity, i.e., the one in which the electron has least angular momentum. For this case, the central perturbing force—to which may be attributed the departure of the helium from the hydrogen energy levels—is able to produce the greatest effect. The assumed additional central field causes a rotation of the orbit in its plane, and this feature is of the greatest importance in the original explanation of small Stark effects. The speed of rotation of the orbit and the accompanying departure from the hydrogen levels arise from a common cause—the near approach of the "outer" electron to the nucleus. These are greatest for the sharp term ($l = 0$) and decrease as we pass to the principal, diffuse and succeeding terms with increasing l values. The rotation is

considered uniform (central field) from arguments based upon the correspondence principle for intensities. Without going into the basis of this principle it may be stated that by a process of extrapolation from the conditions corresponding to high quantum numbers, where quantum and classical theories should agree, it is to be anticipated that quantum numbers will change by 1, 2, 3 . . . units according as the fundamental only, or first or second harmonics respectively appear in an analysis of the electron motion. The experimental fact that $\Delta l = \pm 1$, and no other value, is therefore interpretated as evidence that the orbital rotation characteristic of l was uniform.

The time mean position of an electron in an ellipse is on the major axis, three-quarters of the way from the nucleus to the empty focus. For motion of the type considered in the above paragraph, the uniform rotation of the orbit will make the mean position of the electron coincide with the nucleus if we take a period long enough to allow a few revolutions of the orbit. The rapid orbital rotation characteristic of sharp or principal terms prevents any very great modification in the motion by an external electric field. The mean position of the electron will be slightly displaced from the nucleus a distance proportional to the applied electric field.

The frequency relation

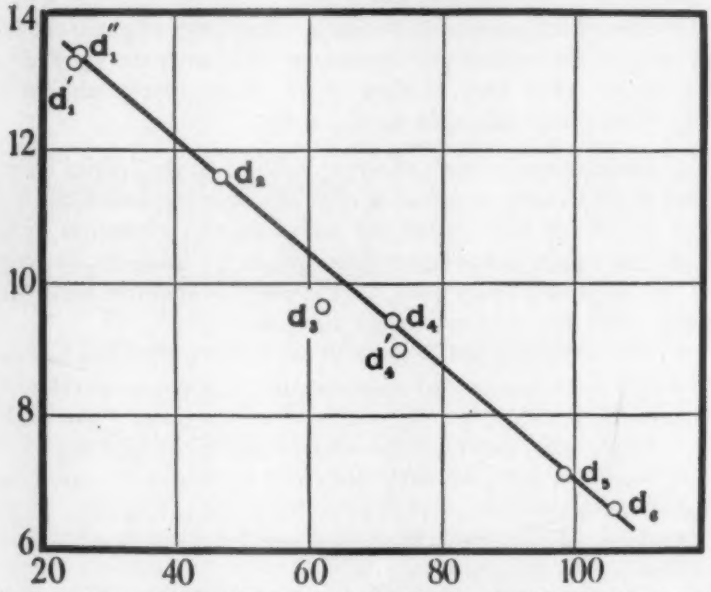
$$E'' - E' = h\nu. \qquad (1)$$

claims that the colour of the light emitted in the Stark effect will depend upon modifications in both initial and final states of the atom. The potential energy with reference to the external field is proportional to the product field times displacement of the electron. Since the mean electron displacement is itself proportional to the field, the energy change is proportional to the square of the field in both initial and final states. It follows from (1) that the observed Stark shifts should be proportional to the square of the field in the sharp and principal series. As we proceed toward the higher members in each series, the Stark displacements increase owing to a decrease in the speed of rotation of the electron orbit in the initial state. This may be expressed in another way.

The "hydrogen difference" is found by subtracting from

the non-hydrogen-like term under discussion, the hydrogen term defined by the same quantum number n. This is a measure of the speed of rotation of the electron orbit as we have seen. Consequently there is a relation pointed out by Bohr between the hydrogen differences and Stark displacements at a given field strength. This proves to be linear. It is well illustrated by the accompanying (Fig. 12) taken from a

FIG. 12.



Bohr relation between hydrogen differences and Stark displacements (after Foster and Rowles).

paper on the Stark-effect in neon by Dr. Rowles and myself. This holds so long as the hydrogen difference is enough to retain the type of motion considered here.

If the orbit rotates very slowly or not at all, as in hydrogen, then the electrical centre (mean position of electron) is displaced by an amount which may grow gradually over any number of revolutions of the electron in its orbit, with the result that a field—no matter how weak—may produce a large displacement of the electrical centre which is not limited by the field strength but by other conditions. Thus Stark displacements in hydrogen are proportional to the applied field, in agreement with the experiments.

3. *Predictions of Stark displacements in known spectra.* The above quadratic relation allows one to make good estimates of the magnitudes of the Stark effect to be expected in any spectrum where the term values (and therefore the hydrogen differences) are known. Even in his first papers on quantum theory, Bohr used the above ideas to predict that observable Stark effects would be limited to spectra which at least approached a hydrogen-like character. Elsewhere the hydrogen differences are too large. Also in helium and all other complex spectra the visible lines are associated with final states for which the hydrogen difference is very great. This means that the *observed Stark effects* result almost entirely from disturbance in *initial* states.

4. *Limitations of early theory.* Owing to the initial success of the Bohr theory in securing a qualitative explanation of the effect in sharp and principal series of the elements, Stark effects have sometimes been classified as (*a*) *linear* in hydrogen and (*b*) *quadratic* elsewhere. This classification is unnatural, untrue, and unnecessary as we shall see.

A close examination of the diffuse series of helium has been withheld, since for stated reasons the above explanation was not intended to apply. The observations show that it does not. Moreover, even in the sharp and principal series the first theory did not give with sufficient accuracy the coefficient needed to make the theory strictly quantitative. These limitations, along with others, pointed to the need of some revision in the theory.

5. *Displacements of diffuse and combination lines.* In 1923 I obtained some Stark-Lo Surdo photographs in which the analysis was clear over a large range of field strengths on a single plate. These allowed me to make a careful plot showing the relation between field strength and the displacements. It was at once clear that in the diffuse and combination lines the relation could not be described simply as linear or as quadratic. In the best analyses (see Fig. 13) each spectral line presented its own characteristic behaviour. The only common feature was a general tendency for the increment of displacement of each line to become proportional to the field as high fields were approached. The minimum field strength at which the linear relation began to hold varied somewhat from line to line.

6. *A Method of identifying certain combination lines.* The fine zero-field separations of the combination lines used in the above illustration were first observed by Nyquist, and the lines were first fully classified correctly by Bohr. Since the final state is not appreciably affected, the curves of Fig. 13 accurately represent the way in which the initial energy levels are modified over the range of applied electric fields. In this case they are so characteristic as to offer a sure means of identifying the levels. Hence, according to Fig. 11 there should be a group of violet lines showing similar Stark effects since the initial levels are selected from the same group. This

FIG. 13. FIG. 14.

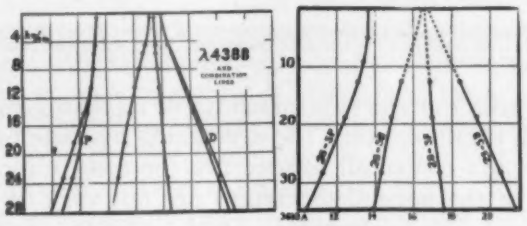


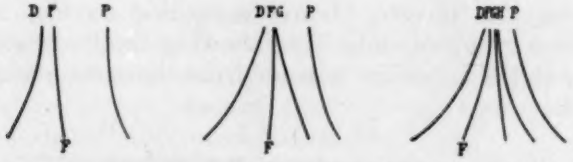
Illustration of method to identify combination lines.

I found to be the case (Fig. 14). The present argument proves that the violet lines were *separate* at zero field, although it was possible to photograph them only in fields so high that the displacements were far too great to allow classification from wave-lengths alone. The proof of this interpretation has been given because a quite different view in which some of these lines were regarded as components of a "diffuse principal" series was first suggested by Professor Stark.

7. *General behaviour of the new lines in electric field.* It is interesting to notice the more general features in the displacements of the new lines, and particularly to follow one of the new series to see the successive changes as we pass from member to member. In Fig. 15, three typical groups of new lines are represented diagrammatically, together with the nearby diffuse lines. If we fix our attention on the F combination lines, we note that the first member has a moderate displacement toward the violet, the second has almost no dis-

placement, and the third is displaced toward the red. This gradual shift from the violet to the red is characteristic of every new series with the exception of the $P - P$ combinations which remain always on the extreme violet edge of the group. Considering now the higher members of these series, it is clear that the hydrogen difference of the initial state grows less,

FIG. 15.



Sketch to illustrate behaviour of the new series in electric fields. For example, the first member of the series $2P - nF$ (marked F) is displaced toward the violet; but in later members the shift is gradually changed to the red.

as the electron's nearest approach to the nucleus grows greater. We notice, therefore, that the decreasing hydrogen differences (being already too small to preserve the rosette motion characteristic of the normal spectrum) are not very directly connected with the observed Stark effects. Indeed, the displacement of a given line is seen to depend, in sign and magnitude, upon its *relative position* in the line group to which it belongs.

8. *Dispersion theory applied to the Stark effect.* At this point the theoretical thread was picked up by Pauli, who explained the main new features through an application of the dispersion theory brought out by Kramers and Heisenberg.

In the dispersion theory formulæ were obtained to give the frequencies and intensities of light emitted by atoms perturbed by the alternating fields of an incident beam of light. Pauli let the frequency of the incident light decrease to zero, and so obtained formulæ to give intensities and displacements of Stark lines in an electrostatic field. The largest of the factors which controlled the intensity and displacement of a given combination line were the separation of the initial level from its immediate neighbours. These separations appeared in the denominator, making the displacement greater the less the separation. Each separation tended to create a displacement in the opposite direction. We notice that these features

are especially well illustrated by the series of F combination lines which we examined a moment ago. For example, in the second group the F line is placed almost mid-way between the D and G lines, and accordingly should have very little displacement. The intensities were investigated in helium first by the author, then by Takamine and Werner, and more extensively by Miss Dewey. A rather satisfactory agreement was found by Dewey for many lines though the $P - P$ combinations were always too strong for this theory. The displacements also were not exactly right for the central lines in each group.

9. *Patterns of the Stark effect in Parhelium.* Early references to regularities in the Stark effect were made by Stark, Yoshida, and others. The initial researches by Stark indicated simple displacements of parallel and perpendicular components of each member of sharp and principal series. There was no splitting. Later investigators seemed to find a fine Stark structure for these lines. This apparently finer analysis appeared without marked regularities. The speculations of Stark regarding the interpretation and behaviour of other series being unsupported, there remained no clear view of the Stark types of splitting comparable to the Zeeman types in magnetic fields.

Reference to the group of Stark patterns which we now know exist in both parhelium and orthohelium was contained in a paper published by the author in the *Physical Review* in 1924. Two of the more complex patterns had been observed at that time; the others were described, and reported later. This research developed from the investigation of intensities. Under favourable conditions it was found that the plates failed to reveal the fine Stark structure previously claimed for the sharp and principal series; yet many new components did appear among the other lines. These changes were of such a kind as to convince one that the Stark patterns in *helium* were actually those implied in Kramers' theory of the relativistic Stark effect in *hydrogen*. This experimental result was the more interesting because it came at a time when there was no adequate notion of the origin of the two systems of spectra in helium, or of the fine structure of orthohelium. The following

patterns observed in orthohelium as well as parhelium therefore represented an unexpected simplicity in the Stark effect for non-hydrogen-like spectra. The plates showed the same pattern or splitting for at least two members of each series as listed in the first column. The l values in the second column are for the initial and final states respectively. Finally, the patterns are represented as fractions; the numerator and denominators being the numbers of "parallel" and "perpendicular" components contributed by the corresponding single lines in the normal spectrum.

Series	$l' - l''$	Pattern
sharp	0 − 1	$\frac{1}{1}$
principal	1 − 0	$\frac{1}{1}$
diffuse	2 − 1	$\frac{2}{3}$

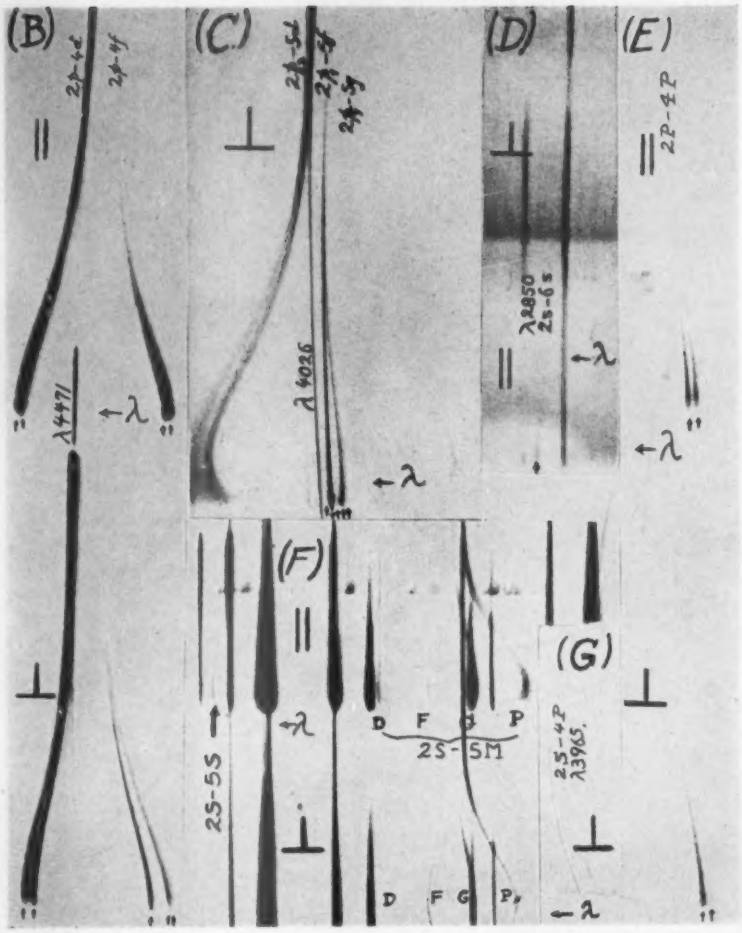
and among the new combination lines:

$S - S$	0 − 0	$\frac{1}{0}$
$P - P$	1 − 1	$\frac{2}{2}$
F, G . . . −P	3, 4 − 1	$\frac{2}{3}$
D, F, G . . . −S	2, 3, 4 − 0	$\frac{1}{1}$

Thus in the visible and ultra-violet spectra of helium there are *four* patterns in the Stark effect, viz. 1/0, 1/1, 2/2, 2/3 in contrast with the uniform normal Zeeman pattern found for all lines in magnetic fields. For illustrations, see Fig. 16 and Plate IV.

The object of the paper by Kramers was to establish the connections between the observed Stark components of hydrogen in high fields and the fine structure of the Balmer lines which was claimed by Sommerfeld on relativistic grounds (Fig. 3). The perturbation methods of Bohr were employed, and the relativistic effects copied by the introduction of a force

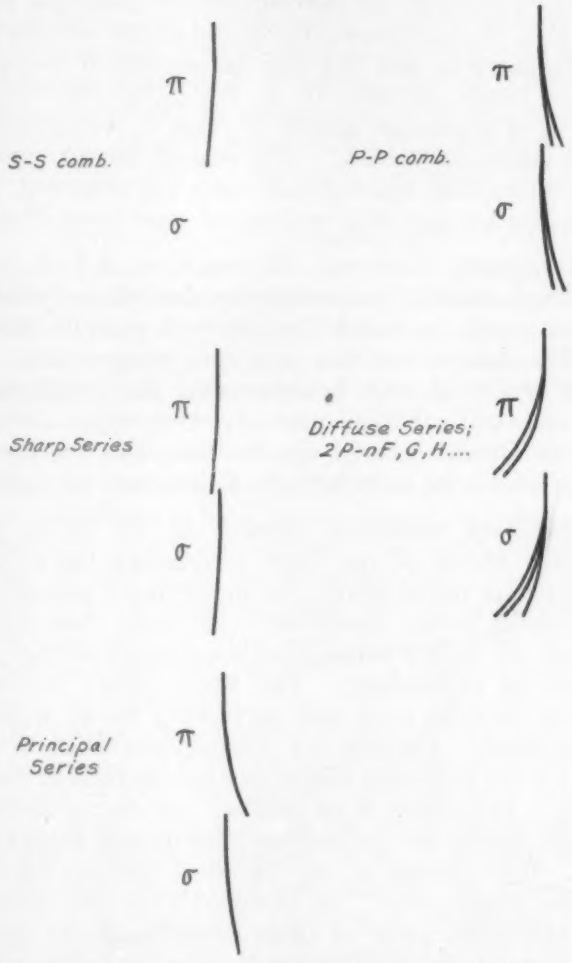
PLATE IV.



Examples of four Stark patterns. Note especially $2S - 5S$, $2S - 5P$, $2P - 4P$, and $2p - 4f$.

which varied inversely as the cube of the distance. The reason this proved to be a suitable model for parhelium is seen from the fact that in the latter spectrum, as Heisenberg has

FIG. 16.



Patterns of the Stark effect in parhelium (Analogue of Preston's rule).

shown, a central force may account for the "hydrogen differences," and there are no complications from the spinning electrons, since they spin in opposite directions. In Kramer's

theory each atom in state n, l so oriented itself with respect to the field that the components of angular momentum along the field took on values $m \cdot h/2\pi$ where $m = 0, \pm 1, \pm 2 \ldots \pm l$. Moreover, the orbit precessed with uniform rate about this axis, and the correspondence principle therefore claimed that in transitions, Δm should equal zero for parallel Stark components and ± 1 for perpendicular components. Thus the Stark pattern of a fine structure component $n'l' - n''l''$ is dependent upon l', l'', that is, is constant within each fine structure "series." For reasons already mentioned in the introduction, these details were not observed, and the hydrogen theory has since undergone very great alterations.

10. *Incomplete Patterns.* Although no helium lines exhibited Stark patterns more complex than those listed above, there were many for which the observed pattern was incomplete. The reason for this was not always clear. Many vanished in low electric fields so that their splitting could not be observed. Either unresolved or weak components might exist in the others—the decision was not made with certainty before the introduction of quantum mechanics.

11. *Quantum mechanics applied to the Stark effect in Parhelium.* Many of the more interesting features in the Stark effect are not explained in an adequate manner by any of the theories so far considered. Recently these have been treated by the author through an application of the quantum mechanics of Heisenberg. The Stark effect in helium is considered, to arise from two perturbing forces applied to a hydrogen atom. The first is a central force which is asked to account for the hydrogen differences as observed in the helium spectrum. That is, it is to produce the effects arising from the double charge on the helium nucleus and from the inner electron. The second is the external electric force which causes the Stark effect. It is found that the terms which express the mean value of these disturbances in the unperturbed system form two independent sets in the matrix which corresponds to the energy due to the perturbations in classical mechanics. By methods developed by Born, Heisenberg and Jordan, this is transformed into a diagonal matrix which then contains a series of total deviations from the original

hydrogen terms, which the group of helium terms experiences under the action of the external electric force. The intensities also are calculated from a knowledge of the terms of a matrix which makes the above transformation. It is found that there is a close connection between the displacement of a Stark component and its intensity. Also it appears that the shift of a particular energy level in the group identified by fixed quantum numbers n, m, cannot be calculated alone—the entire group must be considered. The reader is referred to the complete paper [3] for an account of this interdependence which was recognized but not fully treated in the theory by Pauli.

The application of quantum mechanics was made after the experiments were completed. In Plate V the theoretical results are graphically represented. Displacements were calculated at 10, 20, 30, 40, 60, 80, 100 kv./cm., and curves drawn through the theoretical points. After the theoretical figure was completed, the experimental data were plotted. The agreement is excellent.

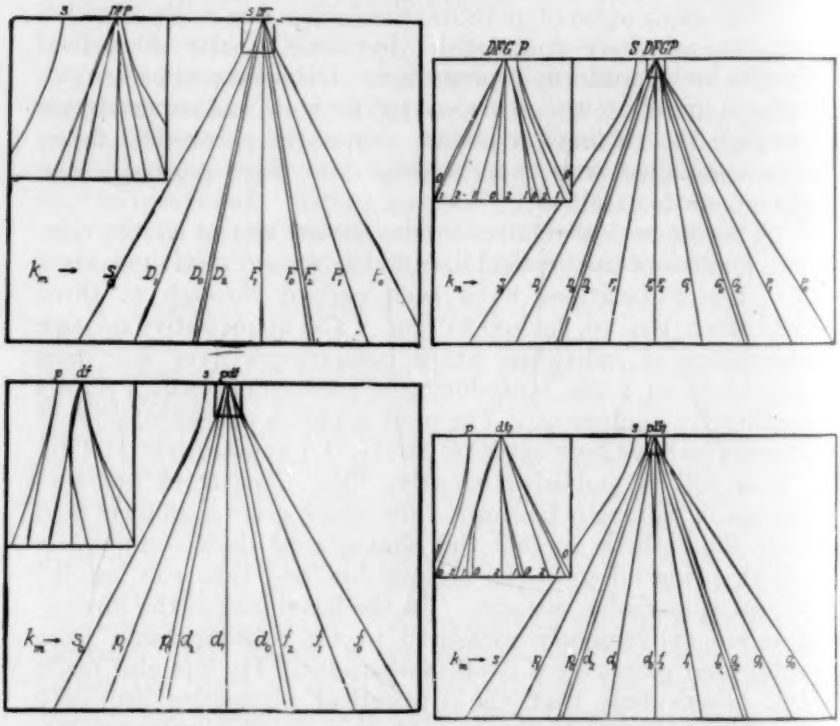
The theoretical relative intensities are shown by the relative lengths of the vertical lines in the second section of Plate V. The calculations have been carried through at three field strengths, 10, 40, 100 kv./cm. The quantitative relative intensities of individual Stark components have not been published so I am reproducing a photograph which shows qualitative agreement. The more accurate determinations of intensities have been made by Mr. G. O. Langstroth at McGill. These will be published shortly. Mr. Langstroth has succeeded in making a Lo Surdo tube which gives a uniform field near the cathode so that the photographs show components which swing off from the original line and then run parallel for an appreciable distance. In the latter region the intensities are conveniently measured in the ordinary way from calibrated plates by a Moll photometer. He has also made the observation that the theoretical intensities are very sensitive to small changes in field strength in the region of low fields. It is therefore necessary to work at fields above 40 kv./cm. in order to be sure that no trouble develops from an

[3] *Roy., Soc. Proc.*, vol. 114, p. 47, 1927.

appreciable error in the determination of the field strength. On the whole the results are in good agreement with theory.

12. *Vanishing components.* Perhaps the most interesting feature in the intensities is the vanishing of certain π components. The expression for the intensity of these components contains a factor which vanishes when the component is displaced to a point under the zero field position of the $P - P$ combination line in the same group. If the fields are high enough to produce a further displacement, the line will eventually reappear. This is well illustrated in the case of the G line in Plates II and V.

FIG. 17.

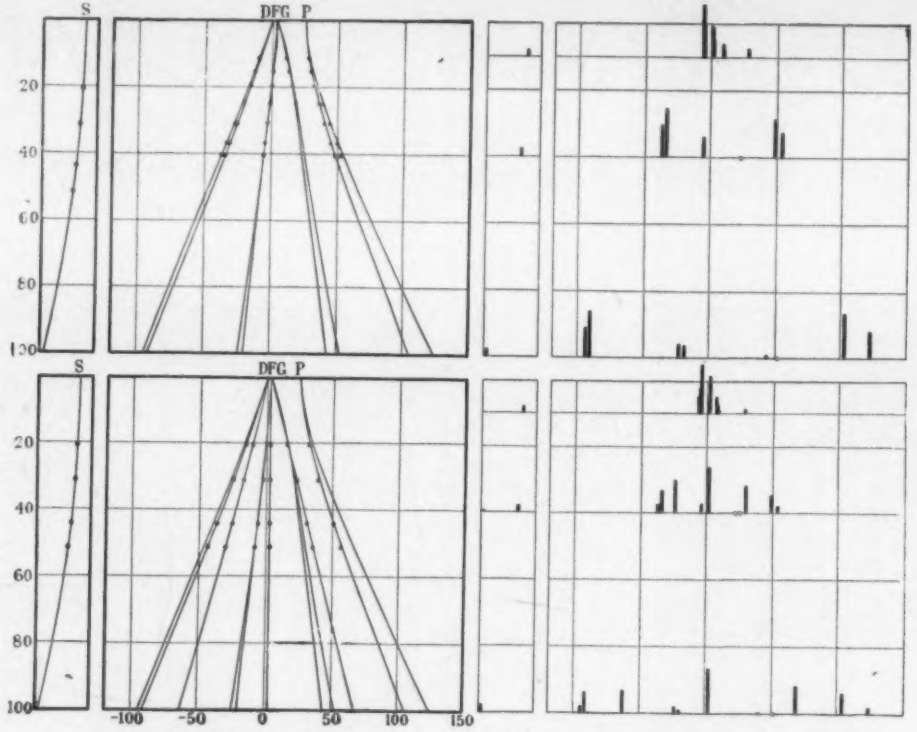


Components of the Helium Groups $2P - 4Q$ and $2p - 4q$ in very high Electric Fields.

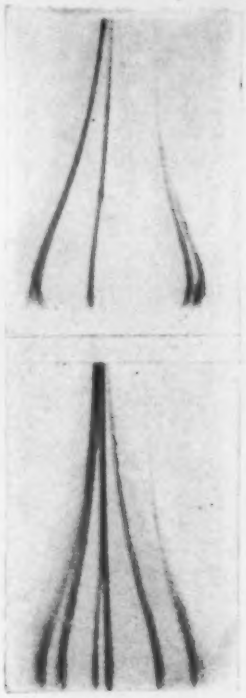
Components of the Helium Groups $2P - 5Q$ and $2p - 5q$ in very high Electric Fields.

13. *Crossing of components.* If we could produce fields high enough to cause Stark displacements very large in comparison with the original separation of the helium lines in

PLATE V.



Theoretical Displacements (with observations plotted). The theoretical Intensities.
The $2P - 5\Omega$ Group ($\lambda 4388$).



Max. Field, 40·4 kv./cm.

the normal spectrum, how would the components then be distributed? This question has been answered by approximate methods, and the result is illustrated in Fig. 17. The connections are drawn in roughly. The details are more clear in the insets. Even the sections there represented deal with events at much higher fields than have so far been attained. It will be seen that many components cross each other. There is experimental evidence that the crossings really occur.

V. COMPARISON OF NORMAL STARK AND ZEEMAN EFFECTS.

Before proceeding with some finer features in the Stark effect, which are concerned with the structure of the original lines in complex spectra, it may prove helpful to review the main facts brought out in the last section. In doing this, it is interesting to contrast this simplest of Stark effects with the normal Zeeman effect found for all lines in the same spectrum. We shall thus recall the complementary character of the two effects which stresses their joint consideration in the detailed study of atoms.

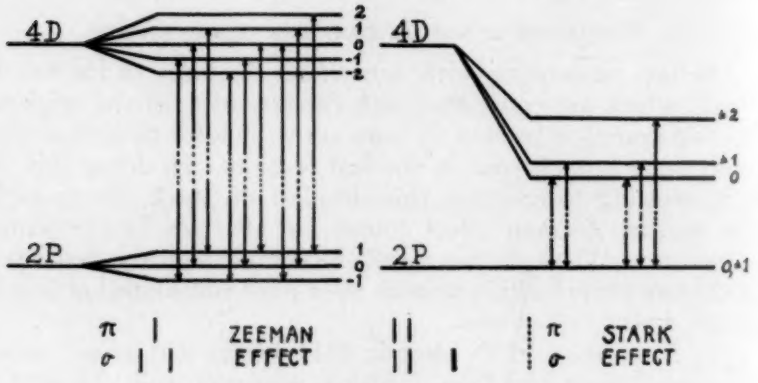
1. *New lines.* The electric field brings out new "combination" lines, i.e. the limiting selection rule $\Delta k = \pm 1$ breaks down. There appears to be no sure evidence that a magnetic field alone ever succeeds in doing this, though it may break the j selection rule within the normal spectrum.

2. *Number of sub-levels.* The change in atomic energy due to an external electric field is independent of the direction of the electron in its orbit, i.e., the change is the same for levels characterised by either plus or minus m. In the magnetic field these levels are symmetrically displaced on either side of the original level. Thus corresponding to an original level n, l, there are $l + 1$ sub-levels in an electric field and $2l + 1$ in a magnetic field.

3. *Displacements of the sub-levels.* Sub-levels arising from a single level in the normal atom are displaced in rather irregular fashion in the Stark effect. As a rule, however, the displacements are all in one direction. The spacing of the sub-levels in the normal Zeeman effect is perfectly uniform throughout the atom. The level which receives no displacement in the Zeeman effect, is just the one which usually has the maximum displacement in the electric field. This reverse

order is followed throughout (as a rule), the sub-level identified by the maximum m value having greatest Zeeman and least Stark displacement. Fig. 18 illustrates these points of difference, and shows how the Stark effect, through its irregular displacements, experimentally reveals the complex nature of the normal Zeeman effect in diffuse series lines.

FIG. 18.



Comparison of Stark with normal Zeeman effect.

4. *Variety of Stark patterns.* The relatively numerous Stark patterns owe their origin mainly to two facts—the small effect in final as compared with initial states, and the new series brought out by the field. As seen in helium, the pattern is constant for the members of a spectral series, i.e. there is an electric analogue to Preston's Rule.

VI. STARK EFFECT IN ORTHOHELIUM

1. *The new feature.* The effect here is very similar to that in parhelium, so long as the fine structure of the orthohelium lines is not observed. Even then, as best seen on these unpublished plates,[4] the two components of the fine structure contribute identical "parhelium" patterns.

It has been customary to assume that the angular momentum due to orbital motion, l, adds vectorially with that from the electron spin, s, to form the resultant, j, which is then

[4] To appear shortly.

resolved along the electric field to give the m values.[5] With $\Delta m = 0 \pm 1$ we should then expect patterns quite different from those observed. This theoretical view really seems incorrect for orthohelium at any field strength.

Obviously the magnetic properties of the spinning electron give the spin more meaning in a magnetic field than in an electric field. In orthohelium we need the spin only to give the observed fine structure of the final state ($2p_{0,(1,2)}$) which remains in the presence of the electric field.

VII. STARK EFFECT IN OTHER COMPLEX SPECTRA.

1. *Patterns largely determined by the quantum number l.* The essential points about the Stark effect in orthohelium appeared on some of my plates in 1924. Encouraged by the indications of parhelium patterns for the fine structure components, the published effects in known spectra were examined to see if there was evidence to prevent the parhelium patterns from being quite general. A few difficulties in the form of apparently *more complex patterns* were found—mainly in neon (Nyquist) and chromium (Anderson). Nevertheless I ventured to suggest that in complex spectra the patterns are controlled by the l (of outer electron) and not the j values. This view met with some adverse criticism when presented to the American Physical Society in Montreal, February, 1926. It has since been supported by Hund * for some cases where the Stark displacement is large compared with the fine structure separations (theoretically high field). A difficulty is seen from the fact that the fine structure separations increase rapidly as we proceed to lower levels of the atom, whereas the Stark effect rapidly decreases. Hence it is usual to find that the field is theoretically "high" in the initial state and "low" in the final state.

2. *Parhelium patterns not universal.* In a re-examination of the effect in neon, Dr. Rowles and I found many examples of incomplete parhelium patterns of diffuse and combination lines—the missing component being normally the most in-

[5] This view comes from following a system through an adiabatic change from external electric to external magnetic field. Cf. H. A. Kramers. *Z. f. Phys.*, **3**, 199 (1920).

* 'Linienspektren,' p. 76 (1927).

tense. Hence it seems clear that under actual experimental conditions the patterns are not always determined by the l values, even if the field is very high in initial state. Neither are they always fixed by the j values, even if the field is "low" in both initial and final states (orthohelium).

3. *Patterns determined by j values.* The analogue of Preston's Rule was established by the investigations in parhelium, where the patterns are determined either by the k or j values, since they are the same. Following this, Ladenburg * has reviewed the researches which allow the latter interpretation.

TABLE.

Element.	Line.	j.	j'.	Pattern.	Observer.
Hg.....	$2p_3$–np_3	0	0	$\frac{1}{0}$	Hansen, Takamine, Werner
Hg.....	$1S$–$2p_2$	1	0	$\frac{1}{1}$	Hanle
Hg.....	$2p_2$–np_2	1	0	$\frac{0}{1}$	Hansen, Takamine and Werner
Na.....	3^2–$3p_2$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	Ladenburg
K.....	4^2–$\frac{5p_2}{6p_2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	Gortrian and Ramsauer

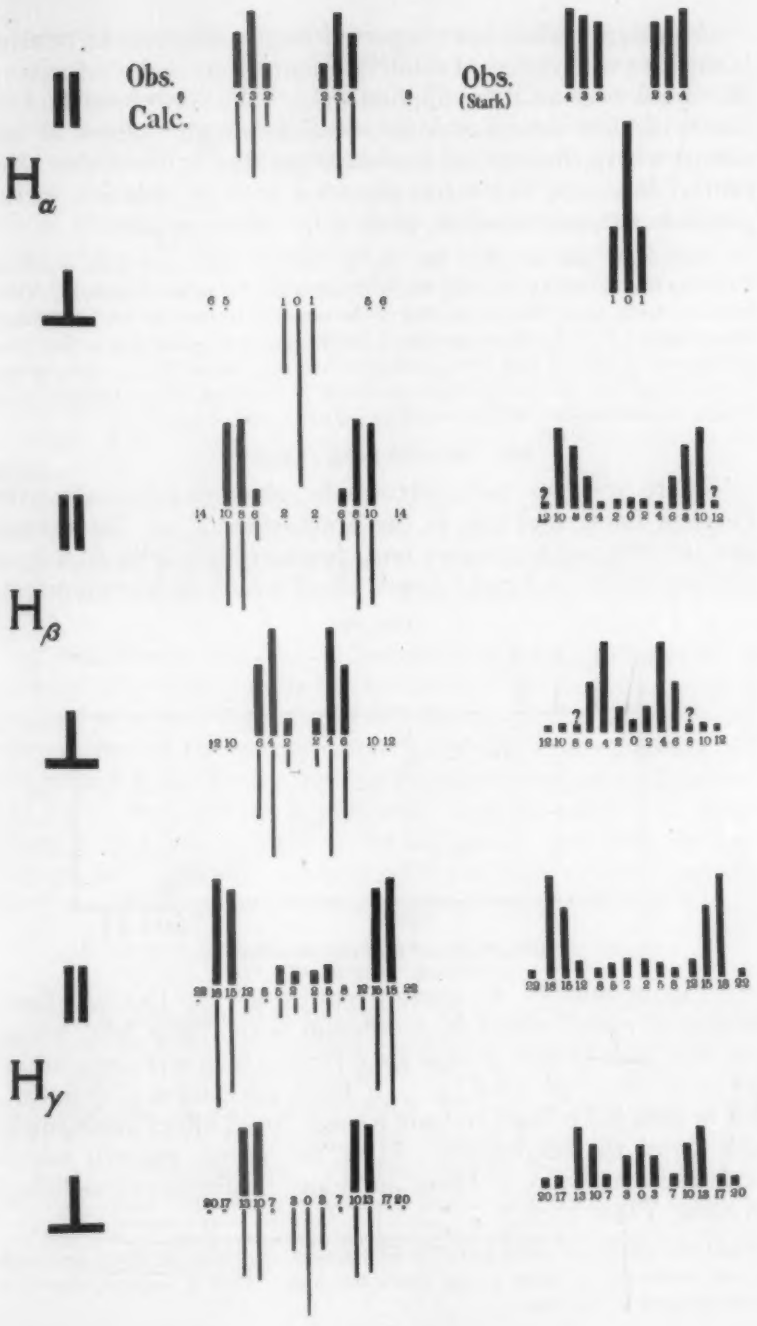
4. *Hydrogen intensities.* Time will not allow a consideration of the effect in hydrogen which Schdapp as well as Rojansky have found according to the new mechanics to be even more complex than Fig. 3.

The recent experimental work in hydrogen has been concerned with a careful examination of intensities of the components in high field which were first observed by Stark. According to Schrödinger the intensities should be somewhat different from Stark's observations in a few cases. In our quantitative experiments at McGill, Dr. L. Chalk and I have found the new calculations by Schrödinger correct within experimental error (Fig. 19).[6]

* 'Phys. Zeit,' No. 12, p. 369 (1929).

[6] Unfortunately our paper contained two errors in regard to the central σ-component of H_α. These accidentally checked and passed unnoticed. We failed to

FIG. 19.



Mark and Wierl have reported large variations in relative intensities with different relative orientations of the velocity of the canal rays and the applied field. We have seen no evidence of this variation from the Schrödinger values in our source where the motion is always parallel to the field. Recently, however, Stark has reported such a variation in the parallel components of H_α from a Lo Surdo source.

Note added March 15th. Mr. D. R. McRae has taken some excellent Lo Surdo photographs of H_α with the large concave grating spectrograph. These leave no doubt about the correctness of the essential features of the Schrödinger intensities for H_α. At the same time it has been a little surprising to find clear evidence of a general lack of symmetry in the separations of the components. Qualitatively, the details are those predicted by Schlapp, who attributed them to fine structure effects which evidently persist in rather high fields.

VIII. PASCHEN-BACK ANALOGUE.

There are two main features in what may be called the Paschen-Back analogue in the Stark effect. (i) The normal fine structure of a complex term fuses in high fields to form a characteristic "normal" Stark effect which lacks symmetry.

FIG. 20.

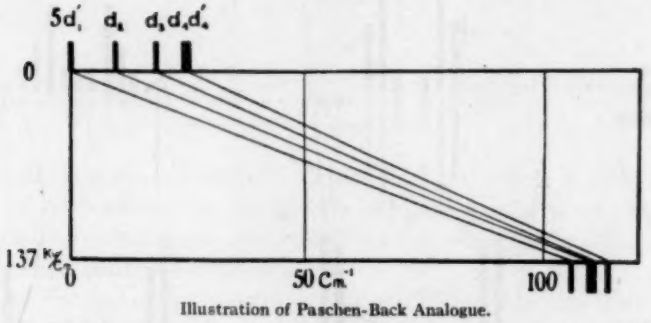


Illustration of Paschen-Back Analogue.

(ii) The symmetry, or second feature of the Paschen-Back analogue, comes about in a different way. The field brings out new lines so that groups are formed which represent initial terms of the type *s.p.d.f.g* . . . Each such term is complex; but in high fields fuses to form a single Stark effect distinguishable from its neighbours. It is the group pattern which possesses symmetry. There are many examples of this effect in neon (Plate 1(*e*)).

double the calculated value given by Schrödinger, as should be done; but even so our redetermined value is now much too high. This is probably due to a superimposed normal line.

IX. EFFECT OF PARALLEL ELECTRIC AND MAGNETIC FIELDS ON THE HELIUM SPECTRUM.

1. *Experimental arrangement.* The effect of parallel fields was first considered by Garbasso who restricted his visual observations to H_α in hydrogen owing to intensity requirements. A source of the Lo Surdo type was placed along the axis of the hollow poles of a Weiss magnet, and the analysis made with a Michelson echelon. Garbasso reported a normal Zeeman splitting of the undisplaced perpendicular Stark component.

In the study of helium, I have placed the axis of the magnet in a vertical position. The slit received light from a source in which the full range of electric fields was represented as usual, and superimposed on this was a uniform magnetic field.

2. *Results in parhelium.* In parhelium the effect is to split each perpendicular Stark component into two components of equal intensity and with normal Zeeman separation. That is to say, the effects are additive. This is seen on the new Plate (2(*d*)).

3. *Additional features in orthohelium.* In addition to a splitting of σ components in orthohelium there are a few fine features of a new type in parallel fields. Some of the Stark components of the weaker member of the fine structure are suppressed, leaving only the single σ component which Paschen and Back observed in a magnetic field of about the same strength (15,000 gauss).[7] The magnetic splitting of the stronger fine structure component is less than normal and the two Zeeman components have unequal intensities.

X. EFFECT OF CROSSED ELECTRIC AND MAGNECTIC FIELDS ON THE HELIUM SPECTRUM.

During the past few months I have succeeded in taking photographs with the applied electric and magnetic fields at right angles. The analyses have been made by both prism and grating spectrographs with exposures running from twenty to ninety minutes. The results have been checked by about twenty plates. A great aid in the experiments is the fact that the light intensity is much greater, for a given

[7] Paschen and Back made observations on the yellow line; mine are for the line $2p$–$5f$ in the λ4026 group.

current through the discharge tube, than that obtained with electric field alone.

At this time I shall limit the report to one general observation. The fundamental combination lines in both parhelium and orthohelium

$$2P - \frac{4F}{5F}, 2p - \frac{4f}{5f}$$

show two to three times the normal magnetic splitting which I have observed for all of them in parallel fields (e.g. Plate 2*d*).

Professor Bohr has interpreted certain unusually large separations in the Zeeman effect for hydrogen (published by Paschen and Back) as due to a small electric field perpendicular to the magnetic field, and brought about by the discharge. This view is supported by my plates, which show a similar effect in H_β.

The present research provides an experimental method by which one may be sure the fields are crossed and allows observations to be repeated. The results indicate that there is an analogue to Preston's Rule even in crossed fields; and, in particular, that only certain series have abnormally large magnetic separations.[8] A more complete report of this work will be given in a later paper. The research is aided by the National Research Council of Canada.

[8] This suggests that the effects in hydrogen may be attributed to *certain members* in the *fine structure* only.

THE POTENTIAL FALL BETWEEN STRIÆ IN ELECTRICAL DISCHARGES THROUGH RAREFIED HYDROGEN.

BY

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ABSTRACT.

A study was made of the variation with gas pressure of the potential fall between striæ in the positive column of a discharge through hydrogen because in this gas the distances between the striæ change with pressure in an anomalous manner first noted by Willows. With decrease of pressure the stria distances at first increase, pass through a maximum value and then through a rather sharp minimum value at a pressure between 1 mm. and 2 mm. The color of the striæ was found to be bluish in the pressure region of minimum separation and reddish at other pressures.

The potential fall between the striæ was measured without the use of probes with hydrogen flowing through a tube 1.2 cm. in diameter. The potential fall was found to increase steadily with increase of pressure from 12 volts at 0.25 mm. pressure to 32.6 volts at 3.15 mm. pressure, the current being 6 m.a. Similar values obtained with the gas stationary were between 1 and 2 volts lower. No anomalous change in the potential fall was found in passing through the pressure region of the closely packed bluish striæ. Corrections to the above values were made for the losses of energy suffered by electrons in elastic collisions with molecules while passing between two striæ. These were found to be negligible for pressures below 0.5 mm. and to amount to 7.5 volts at 3.15 mm. The average energies acquired by electrons between striæ at the two pressures are therefore far from equal.

By a special procedure the narrow bluish and the wide reddish striæ were made to co-exist in different parts of the same tube and the energy acquired by electrons between two striæ under these conditions was found to be 13.5 volts for the blue striæ and 19.4 volts for the red ones, the gas pressure being 1.43 mm. and the current 7 m.a.

It does not seem probable that the purity of the gas was different in the different portions of the tube, although some authors maintain that blue striæ are a sign of the presence of impurities in the gas.

It is shown that blue light can only arise from an excited state of the molecule having an energy of at least 14.5 volt-electrons above the ground level. Where the electrons between striæ acquire less than this amount of energy directly from the field it is necessary to suppose that they obtain the addition, needed for raising molecules to the required level, from collisions of the second kind with molecules of impurities having much lower excitation levels than those possessed by hydrogen.

THE ANOMALOUS BEHAVIOR OF STRIÆ IN HYDROGEN.

When an electric discharge through a rarefied gas exhibits a striated positive column, it is a matter of common observation that for a constant current the distance between the striæ increases as the gas pressure is reduced. Willows [1] noted an exception to this rule for discharges in hydrogen when the current flowing was greater than one milliampere (m.a.) in a tube 12 mm. in diameter. He found that while the distance between the striæ increased with reduction of pressure down to a pressure of about 1.5 mm. of mercury, the distance then decreased somewhat for still lower pressures down to a pressure of about 1 mm. after which it again increased as the pressure was reduced further. In some observations made with larger currents than those used by Willows I found at the critical point that for a small reduction in pressure the stria distances were reduced to half value.

The large retrograde change with pressure in the stria distances in hydrogen, accompanied as it is by color changes in the discharge and by other effects, was made the subject of some further study with the special object of learning how the potential drop between striæ varies with change of gas pressure in the region of rapidly changing stria distances. The color of the striæ in the pressure region of minimum separation differs from that at other pressures and there is a question whether different falls of potential between striæ are involved when these color changes occur or whether the electric field intensity alone changes.

For purpose of comparison some measurements are first shown in Fig. 1 on the variation of stria distances with gas pressure which were made for several gases, using the same discharge tube of 1.1 cm. internal diameter and a discharge current of 6 milliamperes in each case.

The hydrogen gas, prepared by electrolysis of pure dilute sulphuric acid, was dried by passage first through calcium chloride and then through a trap cooled with liquid air, which also intercepted vapors coming from the pump and the McLeod pressure gauge. Voltage was supplied by a high potential storage battery.

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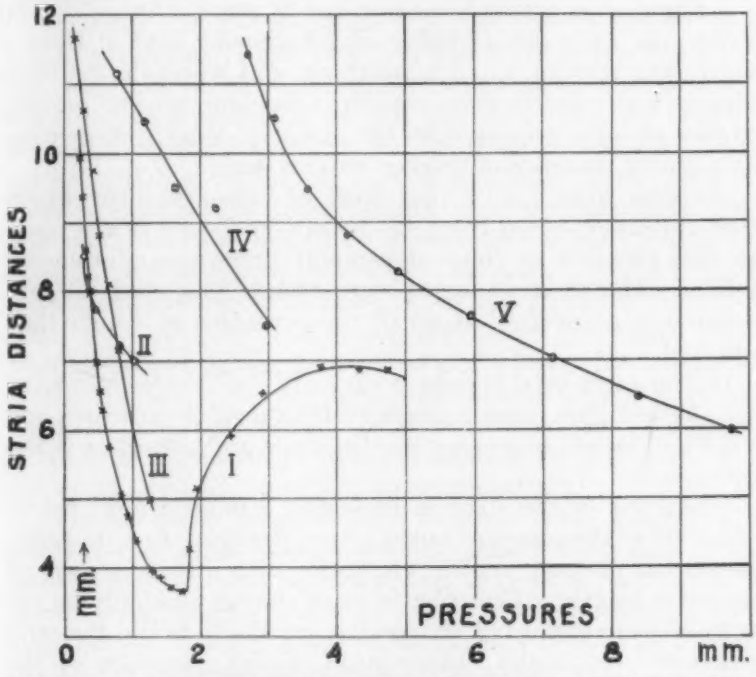
[1] R. S. Willows, *Camb. Phil. Soc. Proc.*, **10**, 302 (1900).

The results for hydrogen are represented by curve I. This curve shows a rather sharp minimum for the stria distances at a pressure of 1.75 mm. of mercury. The other gases used were air, oxygen, argon and helium, and the results for these are shown by curves II–V respectively. The gases were passed through a trap cooled with liquid air to remove

FIG. 1.



Variation of distance between striæ with pressure. Current = 6 m.a. I, Hydrogen; II, Air; III, Oxygen; IV, Argon; V, Helium.

water vapor and any condensable impurities that might be present, but no attempt was made to obtain very pure gases since several authors maintain that striæ cannot be obtained in gases which are highly purified, hydrogen being as yet an exception.

In this connection it may be said that when the helium gas used was purified by aid of a bulb of charcoal immersed in liquid air and by coatings of distilled potassium in the con-

necting tubes, the positive column of the discharge showed no trace of striæ, confirming the observations of Gehloff.[2] The gas still contained some hydrogen and when this was removed by aid of hot copper oxide the positive column again showed no striæ with the exception of one at its cathode end. McCurdy and Dalton [3] who also observed such a single striation ascribed its presence to traces of neon, which was present in the helium they used.

I found that a telephone receiver in the discharge circuit in this case gave out a hissing sound showing that at least a part of the current was intermittent, and when the positive column was viewed in a rapidly revolving mirror uneven patches of light appeared to flit along its length, indicating the possible presence of uneven moving striæ.

As seen from Fig. 1 the range of pressures over which striæ appeared varied from gas to gas, and even in the same gas this range is at times dependent upon minor unknown factors. The striæ in argon were rather hazy and difficult to measure accurately at all of the pressures at which they appeared.

Of the gases used helium is the only one besides hydrogen that showed striæ over a considerable range of pressures and in it the relation between stria distances and pressures is not anomalous.

The color of the striæ in hydrogen was an orange-red at both ends of the pressure range given, changing to a purplish-blue in the pressure region where the stria distances were of minimum length. The color did not change suddenly as the pressure was altered but changed as gradually as did the stria distances. An ocular examination of the spectrum of the striæ indicated throughout the whole pressure range the strong preponderance of the many-lined molecular spectrum as already reported by others [4]; the relative intensities of the lines being apparently somewhat different in the regions of pressure mentioned above and thus accounting for the different appearance of the striæ.

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[2] G. Gehloff, *Verh. d. D. Phys. Ges.*, **14**, 960 (1912).

[3] W. H. McCurdy and P. Dalton, *Phys. Rev.*, **27**, 163 (1926).

[4] P. Neubert, *Ann. d. Physik*, **42**, 1454 (1913). R. Seeliger, *Ann. d. Physik*, **67**, 352 (1922). D. A. Keys, *Canada Roy. Soc. Trans.*, III, **19**, 143 (1925).

POTENTIAL DROP BETWEEN STRIÆ IN HYDROGEN.

Measurements were next made of the potential drop between striæ in hydrogen over the whole available pressure range with a constant discharge current flowing through the tube. This potential drop is generally thought to be intimately connected with the energy electrons must possess to enable them to ionize the gas or to raise its molecules to excited states.

The discharge tube which was used for the results to be given was about 70 cm. long and had an internal diameter of 1.2 cm. The anode was movable and consisted of an aluminum rod surrounded by an iron collar by which it could be moved along the length of the tube from the outside. With the exception of its tip end, the whole anode was enclosed in a glass sheath which fitted closely into the discharge tube. The electrode was joined by a long helical spring to a wire connection sealed into the end of the tube. It was not possible to outgas the metal parts in the tube, and the glass walls were only partially freed of occluded gases by heating with a Bunsen burner during continuous pumping. The magnitude of the discharge current used was limited to about 10 m.a. owing to danger of melting the aluminum cathode. A stream of air was continuously directed against the cathode end of the discharge tube to reduce its temperature.

The potential drop between adjacent striæ was obtained without the use of probes and was found from two voltage measurements across the whole discharge tube taken with the same current flowing, one with a small number of striæ present and another with the anode farther removed from the cathode so that an increased number of striæ was formed.

During the movement of the anode, the cathode end of the positive column remains practically stationary, and correction was made for any slight motion when it occurred. It is assumed that for the two positions of the anode the fall of potential between the cathode and the first stria remains unchanged. This is not true unless the gas pressure is kept constant. At the lowest pressures used the cathode fall of potential increases rapidly with decrease of pressure and at these pressures the gas was being adsorbed at a sufficient rate between the two voltage readings to introduce a considerable

error in the measurements. To obviate this difficulty arising from gas adsorption and to prevent the accumulation in the tube of any impurities that might be released by the discharge from the electrodes or from the glass walls, measurements on the potential fall between striæ were made with a steady stream of pure hydrogen flowing through the discharge tube.

The hydrogen was let into the discharge tube through a variable sensitive valve of the plunger type described by Hopfield [5] and a similar coarser valve was placed between the tube and the diffusion pump. Traps cooled with liquid air were placed at both sides of the discharge tube but even after continuous action for several days it was usually possible to find traces of the mercury spectrum in the negative glow of the discharge, the mercury in all likelihood being liberated from the aluminum cathode which must have become contaminated with it at some previous time.

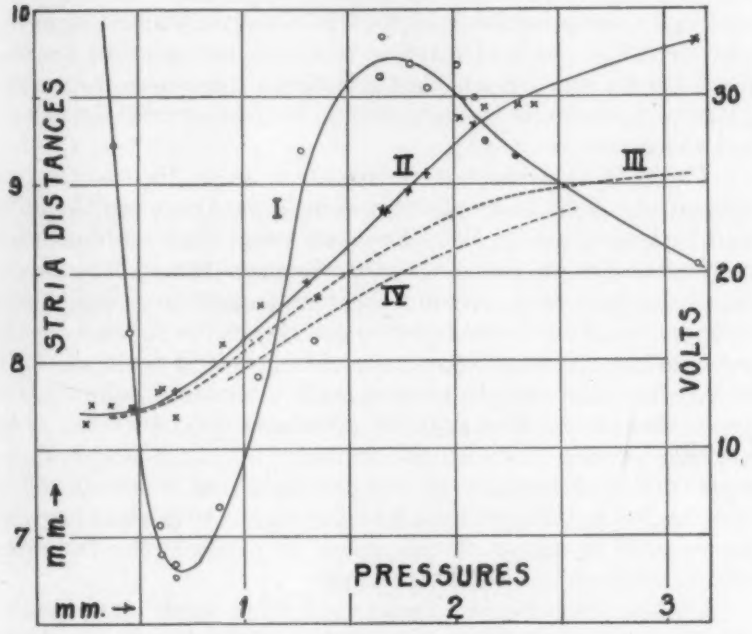
One set of results obtained in this way, when the discharge current was 6 m.a., is represented by the curves in Fig. 2. Hydrogen was admitted into the discharge tube at the rate of about 0.013 c.c. of gas at atmospheric pressure per second, so that at a pressure of 0.6 mm. in the tube the flow velocity through the tube was about 14 cm. per sec., and correspondingly less at higher pressures. Curve I shows the relation between the stria distances and the pressures of the gas. It is seen to be of the same form as curve I in Fig. 1 where the gas was stationary. The current used in the two cases was the same and the tube diameter very nearly so. The stria distances in Fig. 2 are however as a whole larger than those of Fig. 1, and the minimum of the stria distance curve is found at a lower pressure. Differences of this kind in the stria distances in different sets of observations were usual but the potential drops between striæ determined at the same times did not show variations related to or at all commensurate with these. One is led to assume that the variable element producing these changes of stria distances has its seat at the surface of the glass walls of the tube and that small differences in the conditions at this surface which have a large influence on the separation of the striæ have a much smaller effect on the total potential drop between them. This was to be ex-

[5] J. J. Hopfield, *J. O. S. A. & R. S. I.*, **12**, 391 (1926).

pected if these potential drops determine a definite energy needed by electrons to enable them to produce a given action.

The falls of potential between striæ at different pressures, which were measured at the same time as the stria distances of curve I, are given by curve II. The values are seen to increase continuously from approximately 12 volts at a

FIG. 2.



Hydrogen. Current = 6 m.a. Gas flowing.
I. Distance between striæ vs. pressure.
II. Potential fall between striæ.
III. Energy acquired by electrons between striæ.
IV. Energy acquired by electrons between striæ. Gas stationary.

pressure of 0.5 mm. to 32.6 volts at a pressure of 3.15 mm. Below 0.5 mm. the value changes but little down to 0.25 mm., the lowest pressure used. Curve II has none of the compound character of curve I.

This result seems to indicate that as far as the energy acquired by electrons in the field between striæ is concerned, there is nothing abnormal about the closely packed bluish striæ observed at the pressure of the minimum of curve I.

The main difference appears to consist of a greater average field intensity among the bluish striæ. Other results to be described presently appear to show a more fundamental difference.

The voltage drops per stria given by curve II of Fig. 2 do not represent accurately the energies acquired by electrons in traversing the space between striæ because at pressures as high as those used the electrons lose by collision with neutral molecules an appreciable part of the energy obtained from the electric field. It is of interest to make a correction for this loss in order to learn whether at different pressures the energy gained by electrons in their motion between two striæ is or is not the same.

There is at present some question as to the nature and magnitude of the losses that occur at impact between electrons and hydrogen molecules. Townsend and Bailey [6] from their measurements on the motion of electrons through hydrogen conclude that at a pressure of 1 mm. and in fields of the strength used in these experiments the electron loses on the average at each impact with a molecule over 2 per cent. of its energy and that the electrons acquire a terminal velocity that gives them a mean energy of approximately 3 volts. This average energy is so small compared to that required for excitation or ionization of the molecule that it would not be possible for a sufficient number of electrons to possess energies far enough in excess of this mean to produce the luminous effects observed in discharge tubes.

Franck and Hertz [7] concluded from their experiments that slow electrons after moving through hydrogen a distance equal to a few free path lengths suffer small but appreciable losses in energy. The nature of their results does not permit an evaluation of the loss per collision.

Jones and Whiddington [8] have measured directly by a method of magnetic separation the losses suffered by individual electrons by single impacts with hydrogen molecules and have found for electrons having energies between 13 volts and 26 volts that there are some which lose 12.26 volts and

[6] J. S. Townsend and V. A. Bailey, *Phil. Mag.*, **42**, 873 (1921).

[7] J. Franck and G. Hertz, *Verh. d. D. Phys. Ges.*, **15**, 373 and 613 (1913).

[8] H. Jones and R. Whiddington, *Phil. Mag.*, **6**, 899 (1928).

others that lose a less definite amount extending from about 9 volts to 8 volts or less. The first value is sufficient for excitation of the molecule, the second is not. Nor does this second value agree with the energy of dissociation of the hydrogen molecule which is about 4.3 volts. Moreover there is evidence that dissociation in hydrogen does not occur without a concomitant excitation of one of the atoms.

Harnwell [9] has also measured impact losses of electrons in hydrogen, using a different method of detection, and for electrons with initial energies of 180 volts he too finds a prominent number with a low loss of 5.5 volts to 7.5 volts in addition to others with losses of larger amounts up to over 40 volts.

It is not possible at present to make correction for occasional losses of energy of a few volts per impact that may befall some electrons while they are acquiring an energy sufficient for excitation or ionization of molecules. Such losses must however occur very infrequently or else the electron could never obtain in moderate fields enough energy for this excitation or ionization. We shall of necessity confine ourselves then to finding the much smaller losses suffered by elastic collisions alone. Under such circumstances and when the molecular energy is small compared to that of the electron, the energy U (in volts) possessed by an electron after moving a distance x cm. in the direction of an electric field of E volts per cm. is given by Compton [10] as

$$U = \frac{E}{a} \cdot \frac{\epsilon^{2ax} - 1}{\epsilon^{2ax} + 1},$$

where

$$a = \sqrt{\frac{4.536 p^2 m}{l^2 M}},$$

p being the pressure of the gas in millimeters of mercury, l the mean free path of an electron in the gas under a pressure of 1 mm., m the mass of the electron, and M the mass of a molecule of the gas.

In applying the formula, an average value of the electric field across a stria was taken for E. To compute l, it was

[9] G. P. Harnwell, *Phys. Rev.*, **34**, 661 (1929).

[10] K. T. Compton, *Phys. Rev.*, **22**, 339 (1923).

necessary to measure the temperature of the gas in the positive column of the discharge tube. This temperature was obtained approximately by measuring the temperature of the outside wall of the discharge tube by means of a thermocouple made of fine wires, which was held against the wall of the tube by a narrow strip of asbestos paper. A computation showed that for transference of heat through the glass wall of the tube at the rate it was being developed by the discharge the inner wall needed to be less than 0.5° C. above the outer wall. The order of the temperatures found for a discharge current of 6 m.a. may be noted from the representative values that at a gas pressure of 1 mm. the temperature found was 45° C., and at a pressure of 2.5 mm. the temperature was 55° C., the room temperature being 21° C.

The energies acquired by electrons in passing from one stria to the next as computed by the method just indicated are given in volts by curve III of Fig. 2. The correction for loss of energy by elastic impact with molecules as indicated by the difference between Curves II and III is 7.5 volts at the highest pressure used and is almost negligible at the lowest pressure used, but the correction does not suffice to equalize the energy values at the two pressure extremes.

In the computation just made the hydrogen was assumed to be in the molecular state. A portion of it was doubtless in the atomic state. The error introduced by not knowing the relative proportion of atoms and molecules present is however quite small, since a calculation made for one case on the assumption that the gas was all atomic decreased the value of the energy acquired by an electron by less than 2 per cent.

Curve IV of Fig. 2 represents results obtained for the energy acquired by an electron in moving between two striæ when the hydrogen gas was not renewed by flow during the measurements, the discharge current being 6 m.a. as before. The values are seen to be displaced downward from those obtained with the flowing gas.

As the energy acquired by electrons between striæ rises steadily with increase of pressure within the pressure range used, we are confronted with the question of why it is that within this pressure range the striæ appear at first reddish,

then bluish, and finally reddish again. It has been generally assumed that the probability of an electron producing an excited state of a molecule, on collision with it, is greatest when the impinging electron has a kinetic energy not far from that requisite for the production of the excited state, collisions being less efficacious in this regard as the energy of the electrons increases above this value. The recent work of Brasefield [11] on the intensity of the spectral lines of hydrogen as a function of the electronic energy producing the excitation shows a different relation and may be of significance in connection with the color change here under consideration. He found that the intensity of the lines in the triplet system of molecular hydrogen increased as the energy of the exciting electrons decreased from 220 volts to 19 volts, the lowest value used, and appeared to be approaching a maximum at some voltage below 19 volts. On the other hand the intensity of the lines of the singlet system showed a rather sharp maximum for electronic energies between 30 volts and 35 volts. Under a behavior of this character it might be possible for the lines of one system to predominate both for low and high velocity electrons and yet be surpassed in brightness by the lines of another system for an intermediate limited range of velocities, as was found to be the case with the reddish and bluish striæ now under consideration.

COEXISTENCE OF RED AND BLUE STRIÆ.

The conditions which determine the kind of striæ which appear in a discharge through hydrogen are not governed solely by the pressure of the gas. The magnitude of the discharge current is of importance in this regard under some circumstances. Other factors, too, must enter, for the early photographs of such discharges given by de la Rue and Müller [12] show an example where both closely packed and widely separated striæ coexist. Neubert [4] too obtained different kinds of striæ simultaneously in a tube of uniform cross section. With pure hydrogen flowing steadily through a tube 12.4 mm. in internal diameter, I found it possible to obtain at the same time at will both the short spaced bluish striæ and

[11] C. J. Brasefield, *Phys. Rev.*, **34**, 431 (1929).
[12] W. de la Rue and H. W. Müller, *Lond. Phil. Trans.*, pt. 1, 155 (1878).

the longer spaced reddish ones which have been described. With a current of 7 m.a. and a pressure of 1.43 mm. the striæ were normally all of the reddish type and when the current was increased somewhat they all changed to the more numerous bluish kind. On reducing the current very gradually at this stage some of the bluish striæ, usually at both ends of the positive column, would be replaced by a smaller number of the reddish ones. There was thus a fairly stable condition present in one part of the discharge tube which was suitable for the existence of bluish striæ, and at the same time there was present a stable condition for reddish striæ in another part of the tube.

This coexistence of the two types of striæ made it possible to determine the fall of potential between striæ of the two types at almost the same time and hence under identical conditions of gas purity and gas pressure. With a gas pressure of 1.43 mm. and 1,198 volts across the electrodes of the tube, the current produced was 7 m.a. when the positive column consisted (*A*) of 24 bluish and 16 reddish striæ. On reducing the current until the bluish striæ disappeared and then increasing it back to 7 m.a., the positive column with its head at the same position as before was now made up (*B*) of 29 reddish striæ alone and the potential drop across the tube was now 1,131 volts. The anode was now moved until the positive column was reduced (*C*) to 4 striæ, the potential drop across the tube with a current of 7 m.a. being 632 volts.

The distance between the reddish striæ was found to be 6.7 mm. and that between the bluish striæ was 3.9 mm. The voltage drop between the reddish striæ was found from (*B*) and (*C*) to be 20.2 volts, after making a correction for the unequal distances in the two cases between the anode and its nearest stria. The voltage between the cathode and the first stria was obtained from the total voltage across the tube and from the above potential drop between striæ; and on applying the two values to (*A*), the voltage drop between the bluish striæ was found to be 13.7 volts. The average potential gradient in the region of the reddish striæ as found from the stria distances was 30.3 volts per cm. and that across the bluish striæ was 35.0 volts per cm. When correction is made for the loss suffered by the electrons in their elastic impacts

with molecules the energy acquired by them in moving the distance between two striæ becomes 19.4 volts in the reddish striæ and 13.5 volts in the bluish striæ.

The question arises, what is it that is different in the two parts of the tube which makes so large a difference in the appearance of the discharge and in the potential gradient in these two portions? We must seek an explanation in some difference in condition at the surface of the glass walls of the tube. This may consist in differences in the amount of adsorbed gases or in the amount and distribution of surface electric charges or both. At any given pressure these conditions, doubtless influenced by the magnitude of the discharge current, may tend to be stabilized also by the character of the prevailing discharge and tend in turn to maintain the existing form of this discharge. Hence when the current was diminished by only a small amount below the value for which the striæ were all blue, the condition remained stable in its existing form in the central part of the positive column even though at its ends a new arrangement more stable for the new current had set in, under the influence of changes which this current had produced outside of the positive column.

Since electrons after they have fallen through 13.5 volts, at the pressure used, have acquired enough energy to give rise to bluish striæ in one portion of the tube, why do not the electrons in the other portion of the tube occupied by reddish striæ also produce the same bluish light after they have fallen through the same potential difference, instead of going on without apparent action until the potential fall has reached as much as 19.4 volts? A satisfactory explanation of this difference of behavior in different portions of the same tube has not as yet been found. It is stated by some authors that the appearance of blue striæ in a discharge through hydrogen is a sign of the presence of impurities in the gas and Neubert [4] ascribes the effect to oxygen which gets into the gas as a constituent of water, liberated from the walls of the tube by the discharge. It does not seem probable that such an impurity would be present in these experiments in one part of a tube and not in another, especially when fresh hydrogen was continuously flowing through the system. There is however a

possibility that such may be the case, owing to differences of condition established at the walls in different parts of the tube. If this be the explanation here, it is necessary, for an understanding of the behavior indicated by Fig. 2, to assume that only in the region of pressure where the closely packed blue striæ appear in that case does the oxygen given off from the walls form a proper proportion of the mixture to be effective in producing the observed bluish light.

The actual values of 13.5 volts and 19.4 volts for the energy acquired by electrons between striæ in the blue and red regions respectively as well as the large difference between them call for some attention. The radiations must arise here from transitions between excited states of the molecules. The upper of these states for the production of blue light is limited on the lower side by the fact that it must be at least 3 volts above 11.5 volts, the lowest excited level, and it is limited on the upper side by 16.1 volts, the ionization potential. Now 13.5 volts is less than the lower of these limits and 19.4 is greater than the higher of these limits. In the first case where the energy acquired by electrons directly from the field is too small for them to raise a molecule to a sufficiently high state to give rise to the observed visible radiation we must assume that the electrons get the needed additional energy by collisions of the second kind with excited molecules of some impurity like oxygen having much lower excitation levels than those possessed by hydrogen itself. When the electrons acquire from the field an energy greater than that required for the ionization of the molecule we must assume, if the electron loses all of this energy at one inelastic impact, either that both of the electrons in the hydrogen molecules are displaced from their ground levels or that a portion of the energy is used to produce internuclear vibrations.

I am indebted to my assistant, Mr. R. S. Baldwin, for valuable aid with the measurements.

February 26, 1930.

EFFECT OF GRAIN SIZE IN PHOTOGRAPHIC EMULSIONS ON THE FAILURE OF THE RECIPROCITY LAW AND A THEORY OF ITS ORIGIN.*

BY

A. P. H. TRIVELLI and R. P. LOVELAND.

During the past few years L. A. Jones, E. Huse and V. C. Hall [1] of the Kodak Research Laboratories have published in a series of papers the results of very careful studies on the relation between time and intensity in photographic exposures and the failure of the Bunsen-Roscoe reciprocity law $\eta = I.t.$ In this equation η is the insolation or photographic effectiveness of the light exposure, I the intensity of the incident radiation, and t the time of exposure. They found that the relatively high speed large grained materials showed only a slight variation in density resulting from a constant exposure to a widely varying intensity range, as compared with the very marked density variation of the fine grained slower materials. For this reason they considered that there must be a definite relation between the dependence of the photographic effect on intensity (the failure of the reciprocity law) and the size of the grains of the photographic emulsions. "It seems logical to assume that individual grains of great sensitivity have a low value of optimal intensity, and those of low sensitivity a high value." Other things being equal, sensitivity to light increases with the size (projective area) of grain within a given emulsion except in unusual cases. And again, it is reasonable to assume that the smaller grains will have a higher threshold intensity than the larger, and "it

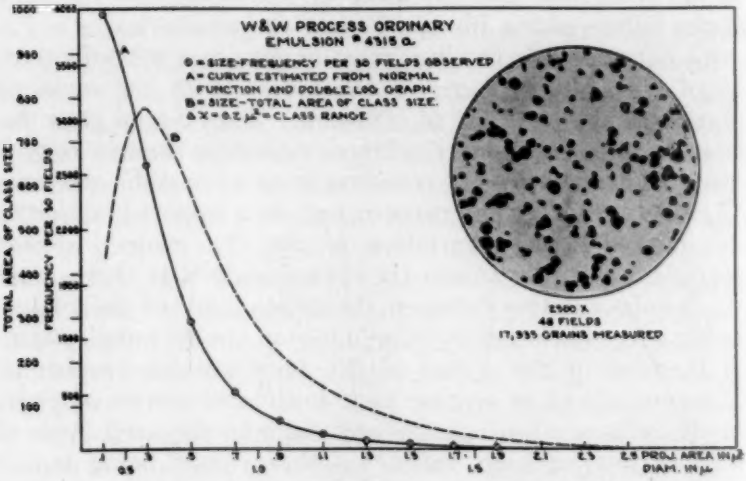
* Communication No. 426 from the Research Laboratories of the Eastman Kodak Company.

[1] Jones, L. A., and Huse, E., "On the Relation between Time and Intensity in Photographic Exposure," *J. Opt. Soc. Amer.*, 7: 1079, 1923; 11: 319, 1925; Jones, L. A., Huse, E., and Hall, V. C., "On the Relation between Time and Intensity in Photographic Exposures," *ibid.*, 12: 321, 1926; Jones, L. A., and Hall, V. C., "On the Relation between Time and Intensity in Photographic Exposure," *ibid.*, 13: 443, 1926.

would seem to follow that the *effective* size-frequency distribution is also dependent upon the intensity." [2]

So far, only the differing *average* grain sizes of various photographic emulsions have been used for comparison. We have now investigated the effect of the different grain sizes on the intensity-time function of exposure within one emulsion by direct optical measurement on single grain layer coatings. (The method has been previously described.)[3] The Wratten Process Ordinary Emulsion was chosen because of its great density variation with change of intensity and because its narrow frequency range of grain sizes as shown in Fig. 1 would

FIG. 1.


W&W PROCESS ORDINARY
EMULSION # 4315 Q.
B = SIZE-FREQUENCY PER 30 FIELDS OBSERVED
A = CURVE ESTIMATED FROM NORMAL FUNCTION AND DOUBLE LOG GRAPH.
B = SIZE-TOTAL AREA OF CLASS SIZE.
Δ X = 0.2 μ² = CLASS RANGE
TOTAL AREA OF CLASS SIZE
FREQUENCY PER 30 FIELDS
2500 X
48 FIELDS
17,935 GRAINS MEASURED
PROJ. AREA IN μ²
DIAM. IN μ

require fewer measurements, and thus shorten the necessarily long and tedious process of measurement. The failure of this emulsion to follow the reciprocity law is very great,[4] as shown

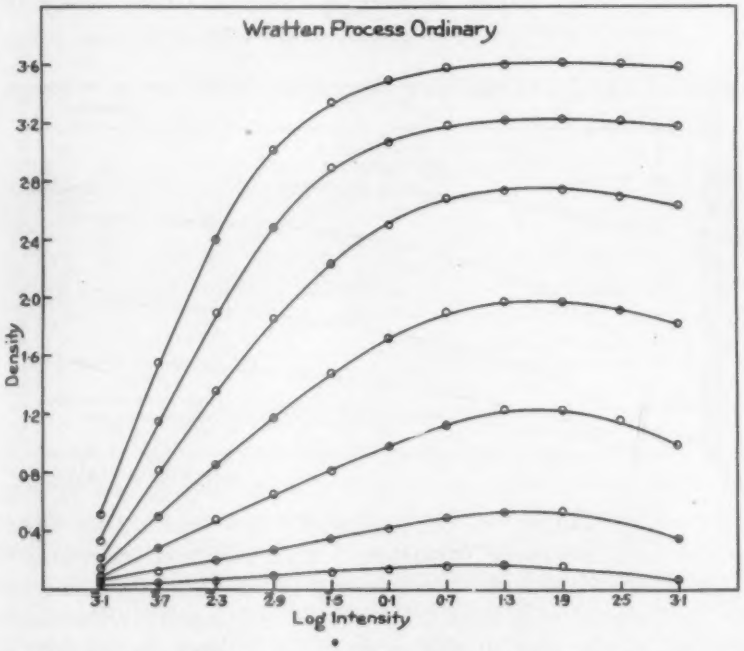
[2] Jones, L. A., Hall, V. C., and Briggs, R. M., "On the Relation between Time and Intensity in Photographic Exposure," *J. Opt. Soc. Amer.*, **14**: 223, 1927.

[3] Wightman, E. P., Trivelli, A. P. H., and Sheppard, S. E., "The Size Frequency Distribution of Particles of Silver Halide in Photographic Emulsions and its Relation to Sensitometric Characteristics, III.," *J. Phys. Chem.*, **27**: 1, 1923. Trivelli, A. P. H., and Loveland, R. P., *J. Roy. Micros. Soc.*, p. 293, 1925.

[4] Jones, L. A., Huse, E., and Hall, V. C., "On the Relation between Time and Intensity in Photographic Exposure," *J. Opt. Soc. Amer.*, **12**: 321 (328), 1926.

in Fig. 2.[5] Our results confirmed the assumptions of L. A. Jones and his collaborators.[6] The small grains within a photographic emulsion are most affected by variation in the intensity level, at least on the low intensity side of the optimum intensity. Moreover, as predicted, the shape of the exposure curve depends upon the intensity, even with single layer grain plates where all the grains can be equally developed

FIG. 2.



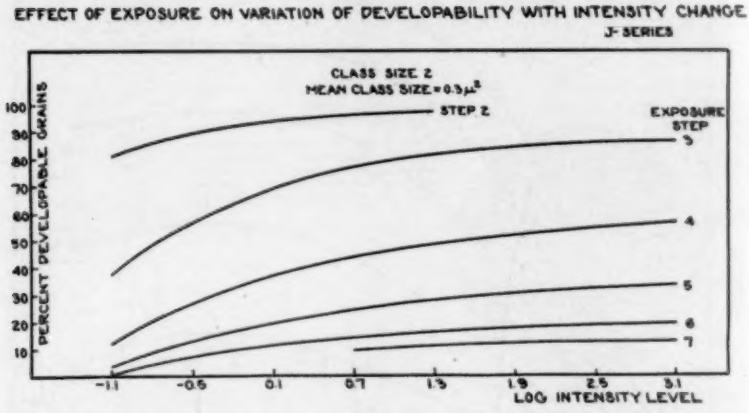
to the region of minimum increase of density (gamma infinity). When the per cent. of affected grains were plotted against the intensity of exposure, making either one curve for each exposure step ($I.t$ = constant) as shown in Fig. 3, or one curve for each class size, it was observed that the curves at the top and bottom were flattened; they correspond to the toes and shoulders of the exposure or sensitivity curves obtained by reading vertically. That is, as the exposure or

[5] Taken from paper by Jones, Huse and Hall.

[6] *Ibid.*

sensitivity increases, the curvature of these intensity curves, for grains of the same sensitivity, increases to a maximum and then decreases again. Therefore, when the range of sensitivity distribution in an emulsion is very wide, as when there is a wide range of grain sizes, these flattened components of the total curve for all grains will decrease the curvature of the latter as compared with the maximum curvature that is attained by a single class size (or sensitivity) at some exposure step. In other words, a wide sensitivity range hides the

FIG. 3.

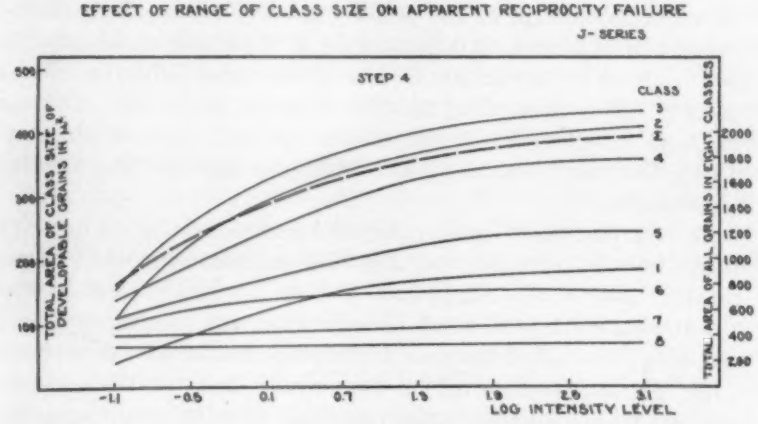


effect of the failure of the reciprocity law and shows flatter curves with intensity variation. This effect is independent of the relative amount of reciprocity failure according to grain size and would still hold true were the intensity effect independent of the size of the grains. It is best shown by the curves of the total projective area of all the grains of one class size plotted against the intensity level. This relation is most representative of the more familiar and applicable density-intensity function and is the function that determines the importance of the various sizes in the total photographic effect. Figure 4 shows the size-area curves obtained when the direct effect of grain size on reciprocity effect is eliminated. The intensity curve of each single class size reaches the curvature exhibited by class 2 and 3 at some exposure, but the curve of the total area presented by all of the grains of eight classes

never reaches this curvature. (The scale of the total area curve should be reduced to correspond to that obtained if all the grains were of class size two or three.)

Added to this effect is the fact that, as the size-frequency distribution becomes wider, the relative contribution of the larger and more sensitive grains to the size area-exposure curves (and hence to the density curves) becomes much

FIG. 4.



greater and the importance of the small grain sizes, with their small area for each grain, falls off extremely rapidly. Therefore, with emulsions of broad size range the contribution of the smallest sizes to the density produced by exposure may be quite negligible. On the surface of the grains of a ripened photographic emulsion are scattered specks of a sensitizing material containing silver sulfide, as has been shown by S. E. Sheppard [7] and which serve during exposure as nuclei for silver-silver sulfide centers of sufficient size to cause the grains to become developable. According to the concentration speck theory, as it has been suggested by S. E. Sheppard, A. P. H. Trivelli and R. P. Loveland [8] the larger grains tend to have

[7] *Colloid Symposium Monograph*, 3: 76, 1925. Sheppard, S. E., "Photographic Gelatin," *Phot. J.*, n.s., 49: 380, 1925.

[8] Sheppard, S. E., Trivelli, A. P. H., and Loveland, R. P., "Studies in Photographic Sensitivity, VI. Formation of the Latent Image," JOUR. FRANK. INST., 200: 51 (75), 1925.

more specks per grain and the larger specks usually occur on the larger grains. This follows from the relative area presented by the various sized grains to the action, during ripening, of the sensitizer in the gelatin. As it will require more silver atoms, and, therefore, more energy from light, to convert the smaller specks into centers of sufficient size to produce developability than those specks more nearly of the size that is spontaneously developable (as emulsion fog) any special effects produced by the energy of exposure should be most evident statistically, in the smaller grains. The effect of the intensity of exposure at constant $I.t$ is obviously a case of this type. These explanations of the differential behavior of the intensity effect according to size of grain and range of sizes hold true irrespective of the choice between any of the sensitivity theories proposed that include a mechanism for this phenomenon.

Among the theories developed to explain the reciprocity failure one is represented by the suggestions of Lüppo-Cramer,[9] and S. E. Sheppard and A. P. H. Trivelli,[10] who propose that with very weak illumination much of the primary light effect is wasted because of its impermanence on account of the predominance, under the conditions, of the reverse reaction. This fails to explain the fact that the photographic effect also decreases at very high intensities with constant $I.t$ H. Kieser [11] also explains the failure of the reciprocity law at low intensities as a regression phenomenon. He states that the silver and bromine atoms set free by light exposure will reunite unless there is a sufficient number of bromine atoms present simultaneously and continuously to form bromine molecules before the reverse reaction can occur. He explains reciprocity failure on the other side of the optimum exposure by bringing in an additional reaction:

$$2Br + H_2O = 2HBr + O,$$

which, he asserts, reverses at high intensities.

[9] Lüppo-Cramer, "Ueber den Schwarzschild-Effekt, *Phot. Ind.*, **25**: 337, 1927.

[10] Sheppard, S. E., and Trivelli, A. P. H.: "Ueber die Empfindlichkeit photographischer Emulsionen und ueber die Theorie der bei ihrer Belichtung sich abspielenden Vorgänge," *Phot. Korr.*, **64**: 273, 1928.

[11] Kieser, H., "Zur Theorie des photographischen Prozesses," *Zt. wiss. Poth.*, **26**: 321, 1929.

If the failure of the reciprocity law is due to regression of the latent image, the effect should be removed by the incorporation of an active bromine absorbent. Lüppo-Cramer reports that when he exposed a plate of a positive emulsion under an Eder-Hecht scale for one minute at 1 meter and another for 49 minutes at 7 meters the latter exposure gave lowered densities. These densities were increased considerably by prebathing in 2 per cent. sodium nitrite or sodium sulfite. Investigators in the Kodak Research Laboratories,[12] however, added various concentrations of acetone semicarbazone to an emulsion and found that the density-intensity curves (at constant $I.t$) were unchanged through an intensity range of over 1 : 1,000,000, although the same treatment will completely remove all solarization effects. This result, together with the fact that regression can relate only to the reciprocity failure at low intensities, makes this first type of theory seem very improbable. Bathing in bromine absorbents sometimes gives increased densities at normal intensities (as has been shown by Lüppo-Cramer and by E. P. Wightman and R. F. Quirk) [13] probably either through a sensitizing effect, or through the removal of solarization of the larger grains in the upper portion of the characteristic curve. Sensitizing by halogen absorbers may be expected to affect the smallest grains the most, since the smallest specks require the most decomposition of silver bromide (and liberation of bromine) to become of developable size. The same thing holds for fine grain emulsions and for photographic emulsions with low sensitivity in general. To prove the removal of the intensity effect it would be necessary actually to show the flattening of the density-intensity curves (at constant $I.t$) since a sensitivity effect would displace them.

A quite different explanation of the reciprocity failure can be deduced from the theory of photographic sensitivity proposed by one of us,[14] and this makes possible an explanation of the phenomenon at both low and high intensities.

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[12] Jones, L. A., and Hall, V. C., paper to be published.

[13] Wightman, E. P., and Quirk, R. F., *Proc. Seventh Intern. Congress*, p. 235, 1928.

[14] Trivelli, A. P. H., "Note on a Tentative Hypothesis of the Latent Image," JOUR. FRANK. INST., **204**: 649, 1927; **205**: 111, 1928.

The theory is based on the known facts that the electrical conductivity of the silver halides and their mixtures and of silver sulfide is increased greatly by illumination, as was discovered by W. Arrhenius,[15] and also that illumination increases the potential difference between silver and silver bromide, as has been shown by E. Becquerel.[16] It is assumed that the potential difference between silver bromide and silver sulfide is also increased. Then if the sensitizing speck consists of silver sulfide with a bit of metallic silver touching it (as experiments seem to prove) [17] a photoelectric cell of the Becquerel type would exist with silver as the cathode, silver sulfide as the anode and the silver bromide as the electrolyte. Upon exposure to light an electric current will flow in a circuit from silver to silver sulfide and through the halide electrolyte, decomposing the latter and causing silver ions to migrate to the cathode. Before exposure ceases or the sulfide becomes entirely surrounded (thus destroying the three phase cell), the speck may grow large enough to be active as a center for the initiation of development.

If photoconductivity of the silver halide lattice of the grains is the basis of photographic sensitivity, the conclusions from experiments on this photoconductivity [18] are sufficient to explain the failure of the photographic reciprocity law. One conclusion is that there is a marked time element in the rise of the electric current upon exposure, or an inertia effect. The photoelectric current *increases* less than proportionally with light intensity.

Obviously then, from low intensities the photographic effect will increase, as does the photoelectric current, with the intensity of illumination. An appreciable time may be taken for the photoelectric current to reach its maximum, and it

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[15] Arrhenius, W., *Sitzungsber. d. Akad. Wiss. Wien*, **96**: 831, 1887.

[16] Becquerel, E., *La Lumière* **2**: 121, 1868.

[17] Wightman, E. P., and Quirk, R. F., "Intensification of the Latent Image on Photographic Plates and Films. II. The Decomposition of Hydrogen Peroxide and the Mechanism of Latent Image Intensification," JOUR. FRANK. INST., 204: 731, 1927; Clark, W., "Oxidizing Agents in the Study of the Sensitivity of Photographic Emulsions," *B. J. Phot.*, **74**: 227, 243, 1927.

[18] Gudden, B., and Pohl, R., "Ueber den zeitlichen Anstieg der lichtelektrischen Leitfähigkeit," *Zt. f. Physik*, **6**: 248, 1921; **7**: 65, 1921; *Physik. Zt.*, 22: 529, 1921.

will be a longer period for the higher maxima at greater intensities. The work of F. C. Toy and Harrison [19] shows that the photoconductance in silver bromide reaches its maximum value in a very short time. This work was probably done at relatively low intensities. The reciprocity law is always investigated by keeping $I.t$ constant, which means that as I increases the time of exposure becomes shorter and shorter. When t equals the time of exposure necessary to reach the maximum conductivity the maximum of the photographic effect (with increasing I at constant $I.t$) will have been reached. From this point the attained maximum of the photoelectric current (and hence the amount of developable density) will become less as the intensity increases.

According to this theory, conductivity differences (variable resistance) of the crystal lattice are very important. Any inclusion in the silver bromide emulsion, such as iodide, should affect the sensitivity relations and possibly the rate of increase of the current, which rate governs the reciprocity effect. In fact, any one of the multitudinous causes for strain in the crystal lattice might be expected to have some effect.

F. C. Toy [20] (quoted by Rawling) suggests, however, that the photo-currents may be electronic, as in metals. According to S. O. Rawling,[20] if Toy's suggestion proves to be correct, this hypothesis must be abandoned. We would go a step further and say that if the photo-current in silver bromide is purely electronic no photochemical decomposition takes place and we must abandon the assumption that the photoconductivity is the photoelectric basis of the formation of the latent image.

B. Gudden and R. Pohl,[21] in their investigations of the photoconductivity of zinc sulfide, showed that this photocurrent is of a complex nature, consisting of: (*a*) fast moving electrons which produce a conductivity as in metals, and (*b*) slow moving electrons, which give electrolytic conductivity and decompose the zinc sulfide, forming zinc at the cathode.

[19] Toy, F. C., and Harrison, G. B., "The Primary Process in the Formation of the Latent Image," *Nature*, **123**: 679, 1929.

[20] Rawling, S. O., "Recent Advances in our Knowledge of the Latent Photographic Image," *Phot. J.*, **69**: 471, 1929.

[21] *Loc. cit.*

The electrolysis of silver halide crystals with the formation of metallic silver at the cathode is a well established fact.[22]

For further study of the failure of the reciprocity law we recommend that investigation be made on the photometric equivalent $\left(P.E. = \frac{\text{grams Ag per sq. cm.}}{\text{Density}} \right)$. The $P.E.$ increases with the size of the grain, that is, the covering power decreases. Other things being equal, the variation of the average grain size can be measured in this way.

SUMMARY.

(1) A test has been made of the conclusions of L. A. Jones *et al* and other investigators of this laboratory to the effect that the degree of failure of the Bunsen-Roscoe reciprocity law, $\eta = I.t$, varies with the size of the grain and that the variation with intensity is greater for the smaller grains.

(2) The smallest sensitivity specks require the most energy of exposure to make them active as development centers and therefore would be most influenced by energy effects such as intensity variation. If the large grains contain most of the larger specks then the smaller grains would be expected to be most affected by intensity variation.

(3) If photoconductivity of the silver halide lattice of the emulsion crystal is the basis of photographic sensitivity then the established facts on the rate of increase of this current upon illumination are sufficient to explain reciprocity failure at both low and high intensities.

[22] Trivelli, A. P. H., "Note on a Tentative Hypothesis of the Latent Image," JOUR. FRANK. INST., **204**: 649, 1927.

DYNAMICAL ANALYSIS OF MACHINES.*

BY

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ANALYSIS OF THE RECIPROCATING ENGINE MECHANISM BY THE METHOD OF SUPERPOSITION OF EFFECTS.

By this method we consider the effects of the applied or external forces and the kinetic reactions as if acting alone separately. It is important to note we must also include the reactions of the constraint set up by the particular system of applied forces or kinetic reactions considered.

1. Effect of the Steam Thrust P:

It is easy to see the piston thrust causes a turning moment on the crank shaft,

$$T_P = Pr \sin \theta + P\frac{r}{l}\sin \theta \cdot r \cos \theta \text{ (approx.)}$$

$$= Pr\left(\sin \theta + \frac{r}{2l}\sin 2\theta\right).$$

An equal and opposite couple on the engine frame:

$$-T_P = P\frac{r}{l}\sin \theta(l \cos \phi + r \cos \theta)$$

$$= Pr\left(\sin \theta + \frac{r}{2l}\sin 2\theta\right) \qquad (\cos \phi = 1 \text{ approx.}).$$

Finally, the steam thrust on the cylinder head is balanced by a thrust at the crank shaft bearing.

It is to be noted that *variation* in the turning moment with its reaction on the frame sets up an oscillation of the frame.

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* Extension of a portion of a dissertation for the degree of doctor of philosophy submitted to Clark University, 1928.

Continued from p. 531, vol. 209, April, 1930.

2. Effect of the Inertia of the Reciprocating Parts (Fig. 45).

The inertia resistance of the reciprocating parts sets up a turning moment:

$$-T_R = -m_R\ddot{x}r\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right)$$

$$= -m_R r^2\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right)^2\ddot{\theta}$$

$$-m_R r^2\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right)\left(\cos\theta + \frac{r}{l}\cos 2\theta\right)\dot{\theta}^2.$$

It is evident if T_R is the resisting torque on the shaft, and T_f is the reacting couple of the frame (Fig. 45):

$$T_R - T_f = 0,$$

$$T_f = T_R = m_R\ddot{x}r\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right).$$

This is also evident since,

$$N_R = Y_R = m_R\ddot{x}\frac{r}{l}\sin\theta$$

and

$$T_f = m_R\ddot{x}\frac{r}{l}\sin\theta(l + r\cos\theta) = m_R\ddot{x}r\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right).$$

The inertia reaction causes, however, an unbalanced thrust on the frame in the line of stroke at the crank shaft bearing of magnitude $X_r = -m_P\ddot{x}_\xi$.

3. Kinetic Reactions of the Connecting Rod (Fig. 46):

The connecting rod inertia effect may be decomposed in various ways. If we introduce weighted masses at the ends, we must introduce the correction couple $M(k^2 - hl)\phi$. The weighted masses at the ends simply add to the reciprocating and revolving weights respectively, with effects corresponding to these inertia reactions.

For the effect of the correction couple, we have:

$$T_c = K'l\cos\phi = M_c(k^2 - hl)\ddot{\phi}.$$

So that from Fig. 1, it is evident that the negative moment on the shaft, is:

$$K'r\cos\theta = T_K = \left(\frac{M_c(k^2 - hl)\ddot{\phi}}{l}\right) r\cos\theta \qquad (\cos\phi = 1).$$

It is further evident the reactions on the frame are K' at the guides and an equal and opposite K' at the crank shaft bearing, where

$$K' = \frac{M_c(k^2 - hl)\ddot{\phi}}{l},$$

so that the moment on the frame is:

$$K'(l + r\cos\theta), \quad \text{since} \quad \cos\phi = 1, \text{ approx.}$$

The reaction on the frame, which reduces to a couple T_f must balance the kinetic reaction of the correction couple, and the torque reaction of the shaft resulting from this couple, so that,

$$\begin{aligned} T_f - T_K &= T_c = K'l\cos\phi; \\ \therefore \quad T_f &= T_K + K'l, \quad \text{since} \quad \cos\phi = 1, \text{ approx.} \\ &= K'(l + r\cos\theta). \end{aligned}$$

The effect of the correction couple T_c on the crank shaft could also be obtained by considering the total mechanism, provided we introduce the reactions of constraints set up by this particular kinetic reaction if acting alone. Taking moments about B, it is evident that the reaction of the guide constraint at A must be a force K' normal to the direction of sliding. Since the inertia reaction due to correction couple is $-T_c = -m_c(k^2 - hl)\ddot{\phi}$, we have, for moments about the crank shaft (Fig. 47):

$$K'(l\cos\phi + r\cos\theta) - T_c = T_K,$$

but, since $K'l\cos\phi = m_c(k^2 - hl)\ddot{\phi} = T_c$,

$$T_K = K'r\cos\theta = \frac{m_c(k^2 - hl)\ddot{\phi}}{l} r\cos\theta.$$

Combining these effects by superposition, we have, for the total torque on the shaft:

$$T = T_P - T_R - T_K - m_0'k_0^2\ddot{\theta},$$

so that:

$$T_P - T = T_R + T_K + m_0'k_0^2\ddot{\theta},$$

where it is to be particularly noted that reciprocating inertia and revolving weight at crank pin radius, are increased by the apportioned connecting rod weight at the corresponding ends of the rod. Substituting the previous values:

$$Pr\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right) - T$$
$$= \left(m_R'r^2\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right)^2 + m_ck'^2\frac{r^2}{l^2}\cos^2\theta + m_0'k_0'^2\right)\ddot{\theta}$$
$$+ \left(m_R'r^2\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right)\left(\cos\theta + \frac{r}{l}\cos 2\theta\right)\right.$$
$$\left. - m_ck'^2\frac{r^2}{2l^2}\sin 2\theta\right)\dot{\theta}^2,$$

which verifies our previous derivations.

Equivalent Mass for Torsional Oscillations of an Engine Mechanism (Fig. 48).—In the torsional oscillation of shafting, it is important to reduce the engine mechanism to an equivalent rotating mass. For the reciprocating mass, in a first approximation neglecting the obliquity of the connecting rod, we have (Fig. 48):

$$x = r(1 - \cos\theta)\quad \frac{dx}{d\theta} = r\sin\theta;$$
$$\therefore\quad A = m_R\left(\frac{dx}{d\theta}\right)^2 = m_Rr^2\sin^2\theta,$$

so that the torsional reaction on the shaft is:

$$T = A\ddot{\theta} + \frac{1}{2}\frac{dA}{d\theta}\dot{\theta}^2$$
$$= m_Rr^2\sin^2\theta\cdot\ddot{\theta} + m_Rr^2\sin\theta\cos\theta\cdot\dot{\theta}^2.$$

The double frequency term $\sin 2\theta$ may be omitted, since its mean value is nil, and its instantaneous value is always small, due to it being a square term in the velocities. Hence, the mean torque is,

$$T_m = \frac{1}{2\pi}\left(\int_0^{2\pi}\sin^2\theta d\theta\right)\cdot m_Rr^2\ddot{\theta} = \frac{1}{2}m_Rr^2\ddot{\theta},$$

FIG. 48

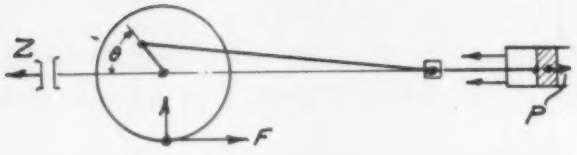


FIG. 49

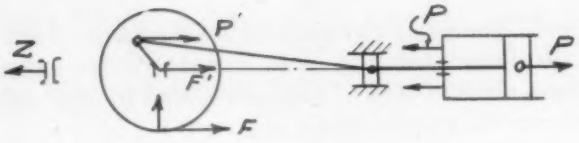


FIG. 50.

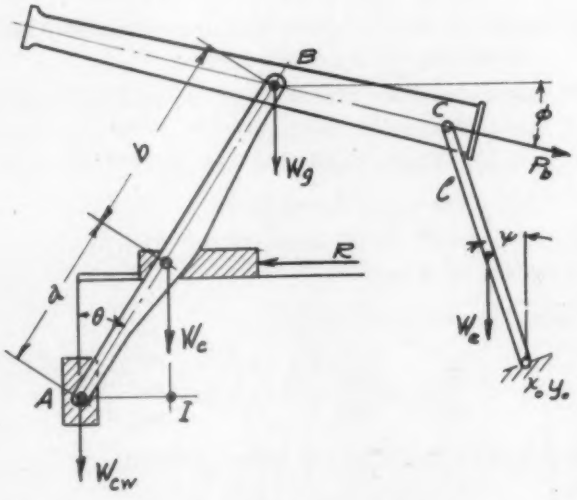


FIG. 51

so that the equivalent rotating mass for torsional oscillations is one-half the reciprocating mass. If we consider the connecting rod as well, omitting the velocity squared term, we have more accurately:

$$T_m = \frac{1}{2}\left[\left(m_R + m_c\frac{l-h}{l}\right)r^2\left(1+\frac{r^2}{4l^2}\right) + m_c(k^2 - hl)\frac{r^2}{l^2}\right]\dot{\theta} + \left(m_0k_0^2 + m_cr^2\frac{h}{l}\right)\dot{\theta},$$

so that the equivalent rotating mass for torsional oscillation at crank pin radius is:

$$\frac{1}{2}\left(m_R + m_c\frac{l-h}{l}\right)\left(1+\frac{r^2}{4l^2}\right) + \frac{m_c}{2r^2}(k^2 - hl)\frac{r^2}{l^2} + m_0\frac{k_0^2}{r^2} + m_c\frac{h}{l}.$$

General Dynamical Equation of a Locomotive (Figs. 49–50). —For simplicity we will only consider the reciprocating mechanism on one side. The extension to any number of cylinders can be readily made (Fig. 49).

Let P = piston load and equal and opposite cylinder thrust, due to steam pressure,
Z = draw bar pull,
F = friction force between wheel and rail,
M_f = mass of frame, boiler and truck wheels, including a term for their rotary inertia,
M_D = mass of driver wheel, k_D = its radius of gyration,
m_R = mass of reciprocating parts,
s = relative displacement of piston,
x = displacement of locomotive,
θ = crank angle from dead center position,
R = radius of wheel.

The equation of motion is:

$$P\frac{ds}{d\theta} - Z\frac{dx}{d\theta} = A\frac{d^2\theta}{dt^2} + \frac{1}{2}\dot{\theta}^2\cdot\frac{dA}{d\theta},$$

since the effective work of the steam pressure is:

$$P(dx + ds) - Pdx = Pds,$$

while the reaction between rail and wheel does no work, as the point of contact of wheel with rail is an instantaneous center. Also,

$$A = M_f\left(\frac{dx}{d\theta}\right)^2 + M_D\left(\frac{dx}{d\theta}\right)^2 + M_D k^2 + m_R\left(\frac{du}{d\theta}\right)^2.$$

The kinematic relations give:

$$s = r(1 - \cos\theta) \qquad x = R\theta \qquad u = r(1 - \cos\theta) + x$$

$$\frac{ds}{d\theta} = r\sin\theta \qquad \frac{dx}{d\theta} = R \qquad \frac{du}{d\theta} = r\sin\theta + \frac{dx}{d\theta},$$

$$= r\sin\theta + R.$$

Therefore,

$$A = M_f R^2 + M_D(R^2 + k_D{}^2) + m_R(r^2\sin^2\theta + 2rR\sin\theta + R^2),$$

$$\frac{dA}{d\theta} = 2m_R r^2\sin\theta\cos\theta + 2rR\cos\theta.$$

The equation of motion, is, therefore,

$$Pr\sin\theta - ZR = \left(M_f R^2 + M_D\left(1 + \frac{k_D{}^2}{R^2}\right)R^2 + m_R r^2\sin^2\theta + 2m_R rR\sin\theta + m_R R^2\right)\ddot{\theta} + m_R\left(r^2\frac{\sin 2\theta}{2} + rR\cos\theta\right)\dot{\theta}^2. \quad (1)$$

This expression is in terms of the coördinate θ, so that the generalized forces are in the nature of moments.

In terms of the tractive forces, we have, since

$$s = r(1 - \cos\theta), \qquad x = R\theta,$$

$$\frac{ds}{dx} = \frac{r\sin\theta}{R}; \qquad \therefore \quad P\frac{ds}{dx} = P\frac{r\sin\theta}{R},$$

so that

$$P\frac{ds}{dx} - Z = \left(M_f + M_D\left(1 + \frac{k_D{}^2}{R^2}\right) + m_R\frac{r^2}{R^2}\sin^2\theta + m_R + 2m_R\frac{r}{R}\sin\theta\right)\ddot{x} + m_R\left(\frac{r^2}{R^2}\frac{\sin 2\theta}{2} + \frac{r\cos\theta}{R^2}\right)\dot{x}^2.$$

To estimate the mean value per revolution, we note:

$$\frac{1}{2\pi}\int_0^{2\pi}\frac{Pr\sin\theta d\theta}{R}=\int_0^{2\pi}\frac{Pr\sin\theta d\theta}{R}=\frac{2Pr}{\pi R},$$

since the torque changes sign on the return stroke, and is therefore always positive. On the other hand, the mean value of the periodic terms $\sin\theta$, $\sin 2\theta$ and $\cos\theta$ per revolution is nil. Further,

$$\frac{1}{2\pi}\int_0^{2\pi}\sin^2\theta d\theta=\frac{1}{2},$$

so that, the mean value per revolution of equation is:

$$\frac{2Pr}{\pi R}-Z=\left(M_f+M_D\left(1+\frac{k_D^2}{R^2}\right)+\frac{1}{2}m_R\frac{r^2}{R^2}+m_R\right)\ddot{x},$$

and, since the mass of the total locomotive is:

$$M=M_f+M_D+m_R,$$

we have

$$\frac{2Pr}{\pi R}-Z=\left(M+M_D\frac{k_D^2}{R^2}+\frac{1}{2}m_R\frac{r^2}{R^2}\right)\ddot{x},$$

so that the effect of the reciprocating part is equivalent to one-half their weight at crank pin radius.

We will now consider the derivation of these equations from the synthetic point of view (Fig. 50).

Considering the horizontal reactions on the frame, we have (Fig. 50):

$$F'-P-Z=M_f\ddot{x}, \qquad (1)$$

where F' is the reaction at the journal,
P is the steam thrust on the cylinder head,
Z is the draw bar pull,
M_f is the mass of the locomotive frame, etc.

For the driving wheel alone, we have:

$$P'+F-F'=M_D\ddot{x},$$
$$P'r\sin\theta-FR=M_Dk_D^2\frac{\ddot{x}}{R}$$

R = radius of driver
r = crank radius
M_D = mass of driving wheel

so that,

$$P'\left(\frac{R + r\sin\theta}{R}\right) - F' = M_D\left(1 + \frac{k_D^2}{R^2}\right)\ddot{x}. \qquad (2)$$

Combining (1) and (2):

$$P'\frac{r\sin\theta}{R} = P - P' + \left[M_f + M_D\left(1 + \frac{k_D^2}{R^2}\right)\right]\ddot{x} + Z. \quad (3)$$

Now considering the reciprocating parts, etc., we have:

$$P - P' = m_R(r\sin\theta\ddot{\theta} + r\cos\theta\dot{\theta}^2 + R\ddot{\theta}),$$

so that

$$P - P' = m_R((R + r\sin\theta)\ddot{\theta} + r\cos\theta\dot{\theta}^2)$$

and

$$P' = P - m_R((R + r\sin\theta)\ddot{\theta} + r\cos\theta\dot{\theta}^2).$$

Substituting these values in equation (3), we obtain:

$$Pr\sin\theta - ZR = (m_R(R^2 + 2Rr\sin\theta + r^2\sin^2\theta) + M_fR^2 + M_D\left(1 + \frac{k_D^2}{R^2}\right)R^2\ddot{\theta} + m_R\left(rR\cos\theta + \frac{r^2\sin 2\theta}{2}\right)\dot{\theta}^2.$$

Analysis of Disappearing Gun Carriage Mechanism (Fig. 51).—Though the disappearing gun is now practically obsolete, it offers, however, a splendid example of a fairly complicated dynamical system with one degree of freedom.

Disappearing gun carriages, as evident by their terminology, are designated because in the recoil the gun is brought down below a parapet and disappears from the enemy's view. The gun is loaded in the lower position. By introducing a counterweight, the gun is brought by gravity to the firing position, the gun being above the parapet only during the firing period.

The mechanism consists of a Cardan linkage, the gun lever being constrained at one end to move along vertical guides at the crosshead of the counterweight, the middle of the gun lever being constrained to a horizontal path with the hydraulic recoil cylinder carriage, while its upper end supports the gun trunnions. The c. of g. of the gun is located at the trunnions; that is, at the gun lever support. The rear of the gun is supported by the elevating arm. A feature in the design is to maintain the angular acceleration of the gun small, so that

the thrust along the elevating arm may not be too great. The powder reaction is mainly counteracted by the inertia resistance of the gun and the reactions at the trunnion of the gun lever.

In order to calculate the principal reactions, it is necessary to determine the acceleration of the parts. We will, therefore, obtain the generalized equation of motion of the system relative to the coördinate θ.

Let (Fig. 51):

W_g = weight of the gun "c" with c. of g. at the trunnions,

W_{cw} = weight of counterweight constrained by vertical guides,

W_c = weight of the recoil carriage,

W_r = weight of gun lever or rocker $a - b$ located approximately at the rocker trunnions at the recoil carriage,

W_e = weight of elevating arm,

I_g = moment of inertia of gun about its c. of g.,

I_r = moment of inertia of rocker about its c. of g.,

I_e = moment of inertia of elevating arm about its bottom support,

P_b = powder pressure reaction along axis of bore,

R = hydraulic resistance of recoil cylinder along path of recoil carriage and proportional to the square velocity.

Kinematic Relations—Velocity Ratios and their Derivat ves.—Assuming axis OX and OY as shown, we have:

$$(a + b) \sin \theta + c \cos \phi + l \sin \psi = x_0,$$
$$- b \cos \theta + c \sin \phi + l \cos \psi = y_0.$$

Differentiating,

$$(a + b)\dot{\theta} \cos \theta - c\dot{\phi} \sin \phi = - l\dot{\psi} \cos \psi,$$
$$b\dot{\theta} \sin \theta + c\dot{\phi} \cos \phi = l\dot{\psi} \sin \psi.$$

Multiplying these equations first by $\sin \psi$ and $\cos \psi$, we obtain the velocity ratio:

$$K_{\phi\theta} = \frac{\dot{\phi}}{\dot{\theta}} = - \left[\frac{a \cos \theta \sin \psi + b \sin (\psi + \theta)}{c \cos (\phi + \psi)} \right] = \frac{d\phi}{d\theta}$$

and then by cos ϕ and sin ϕ, we have:

$$K_\theta = \frac{\psi}{\theta} = -\left[\frac{a\cos\theta\cos\phi + b\cos(\theta-\phi)}{l\cos(\psi+\phi)}\right] = \frac{d\psi}{d\theta}.$$

The conditions of the c. of g. of the gun are:

$$x_g = (a+b)\sin\theta, \qquad \dot{x}_g = (a+b)\cos\theta\dot{\theta},$$
$$y_g = -b\cos\theta, \qquad \dot{y}_g = b\sin\theta\cdot\dot{\theta},$$

so that

$$K_{xg\theta} = (a+b)\cos\theta, \qquad K_{yg\theta} = b\sin\theta.$$

In like manner we may show the velocity ratios for the recoil carriage and counterweight are:

$$K_{c\theta} = a\cos\theta, \qquad K_{cw\theta} = -a\sin\theta.$$

For the derivatives of the velocity ratios, since

$$\frac{d\phi}{d\theta} = K_{\phi\theta}, \qquad \frac{d\psi}{d\theta} = K_{\psi\theta},$$

$$\frac{dK_{\phi\theta}}{d\theta} = \frac{a}{C\cos(\phi+\psi)}[\sin\theta\sin\psi - K_{\psi\theta}\cos\theta\cos\psi - \cos\theta\sin\psi\tan(\phi+\psi)(K_{\phi\theta}+K_{\psi\theta})] - \frac{b}{c\cos(\phi+\psi)}[\cos(\psi+\theta)(K_{\psi\theta}+1) + \sin(\psi+\theta)\tan(\phi+\psi)(K_{\phi\theta}+K_{\psi\theta})]$$

$$\frac{dK_{\psi\theta}}{d\theta} = \frac{a}{l\cos(\psi+\phi)}[\sin\theta\cos\phi + K_{\phi\theta}\cos\theta\sin\phi - \cos\theta\cos\phi\tan(\psi+\phi)(K_{\psi\theta}+K_{\phi\theta})] + \frac{b}{l\cos(\phi+\psi)}[\sin(\theta-\phi)(1-K_{\phi\theta}) - \cos(\theta-\phi)\tan(\phi+\psi)(K_{\phi\theta}+K_{\psi\theta})]$$

and

$$\frac{dK_{xg\theta}}{d\theta} = -(a+b)\sin\theta, \qquad \frac{dK_{yg\theta}}{d\theta} = b\cos\theta,$$
$$\frac{dK_{c\theta}}{d\theta} = -a\sin\theta, \qquad \frac{dK_{cw\theta}}{d\theta} = -a\cos\theta.$$

We have now all the kinematic data for determining the

generalized equation of motion. The powder reaction is most conveniently resolved into components $P_b \cos \phi$ and $P_b \sin \phi$, while the weight of the gun acts at the trunnions of the rocker or gun lever support. Let h be the height to the c. of g. along the elevating arm from its fixed axis.

The generalized equation of motion is:

$$[M_g(K_{xg\theta}^2 + K_{yg\theta}^2) + I_g K_{\phi\theta}^2 + (M_c + M_r)K_{c\theta}^2 + M_{cw}K_{cw\theta}^2 + I_r + I_e K_{\psi\theta}^2]\ddot{\theta} + \left[M_g\left(K_{xgc}\frac{dK_{xgc}}{d\theta} + K_{yg\theta}\frac{dK_{yg\theta}}{d\theta}\right) + I_g K_{\phi\theta}\frac{dK_{\phi\theta}}{d\theta} + (M_c + M_r)K_{c\theta}\frac{dK_{c\theta}}{d\theta} + M_{cw}K_{cw\theta}\frac{dK_{cw\theta}}{d\theta} + I_e K_{\psi\theta}\frac{dK_{\psi\theta}}{d\theta}\right]\dot{\theta}^2 = P_b(K_{xg\theta}\cos\phi + K_{yg\theta}\sin\phi) - RK_{c\theta} + W_g K_{yg\theta} + W_{cw}K_{cw\theta} + W_e h K_{\psi\theta}\sin\psi.$$

The solution of this equation is most readily effected by evaluating the centrifugal terms from the equation of energy for the work of the forces from the initial configuration. That is,

$$\frac{1}{2}A\dot{\theta}^2 = \int_0^\theta \Phi d\theta - \int_{\bar{V}_0}^{\bar{V}} \frac{dV}{d\theta}d\theta = \int_0^\theta \Phi d\theta - (V - V_0),$$

where

$$A = M_g(K_{xg\theta}^2 + K_{yg\theta}^2) + I_g K_{\phi\theta}^2 + (M_c + M_r)K_{c\theta}^2 + M_{cw}K_{cw\theta}^2 + I_r + I_e K_{\psi\theta}^2.$$

$$\Phi = P_b(K_{xg\theta}\cos\phi + K_{yg\theta}\sin\phi - RK_{c\theta}).$$

$$V - V_0 = (W_{cw}a - W_g b)(\cos\theta_0 - \cos\theta) - W_e h(\cos\psi_0 - \cos\psi).$$

It is to be noted that in this equation the kinetic and potential energies are readily evaluated, but the integration of the work of the applied driving forces and resistances usually involve a complex integral, since the work forces themselves are usually a complex function of the coördinate.

To determine the powder reaction as a function of the coördinate θ, we must reduce the displacement of the pro-

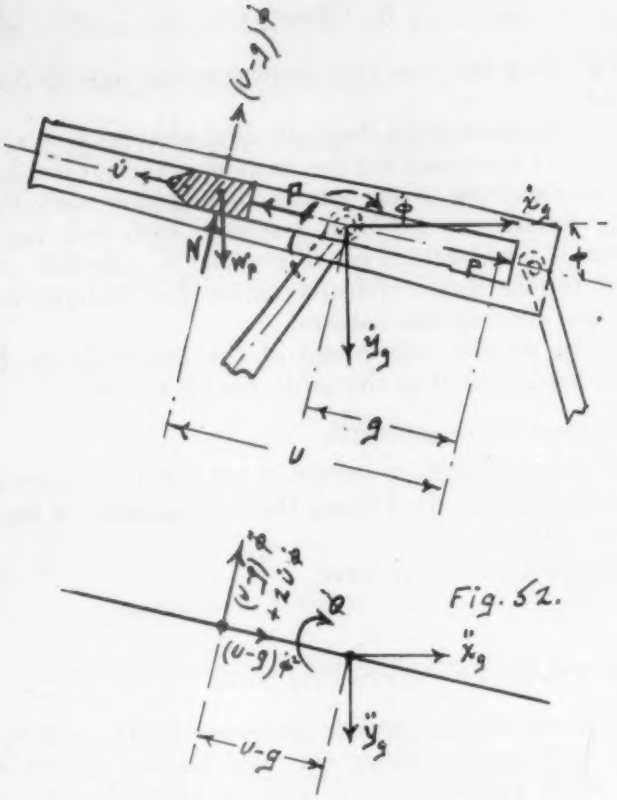


Fig. 52.

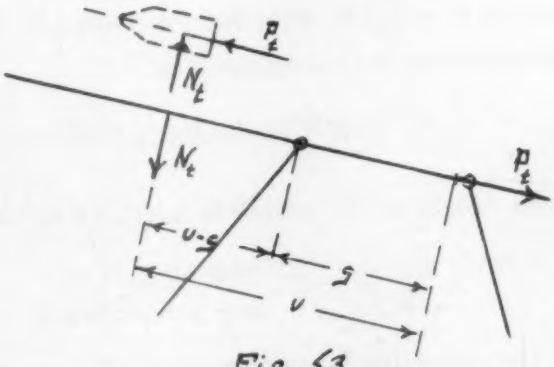


Fig. 53.

jectile U along the bore to a corresponding angular displacement $\Delta\theta$.

On the Reaction of the Projectile-Disappearing Gun Carriage (Fig. 52).—To account for the motion of the projectile in its travel up the bore of the gun in conjunction with the gun carr age mechanism we have a system with two degrees of freedom. Considerable simplification is effected in the analysis by the use of velocity ratios and their derivatives for the gun carriage mechanism.

Let the relative coördinate of the projectile be U, the relative displacement of the projectile up the bore.

m_p = mass of the projectile,
A = the coefficient of inertia of the gun recoil system,
θ = the coördinate defining the configuration of the recoil system,
P = powder pressure force,

then

$A = \Sigma m_s K_{s\theta}^2$, for the recoiling parts.

The work of the powder pressure forces, which react equally and opposite along the bore on the projectile and breech block respectively, is $P\delta u$, so that the generalized force acting on the coördinate U, is P, while the effect on the coördinate θ is nil. The work of the gravitational forces on the recoil parts will be expressed in terms of their potential function, i.e. $= -\frac{dV}{d\theta}\delta\theta$ and the resistance of the recoil cylinder reduced to the coördinate θ, is

$$-R\frac{dx_c}{d\theta} = -RK_{xc\theta}.$$

For the weight of the projectile itself, its virtual work is

$$W_p(\delta y_g - \delta u \sin\phi - (u - g)\cos\phi\delta\phi)$$
$$= W_p(K_{y\theta\theta} - (u - g)K_{\phi\theta}\cos\phi)\delta\theta - \delta u \sin\phi,$$

so that the generalized components of W_p acting on the

coördinates θ and U are, respectively,

$$W_p K_{y\theta} - (u - g)K_{\phi\theta} \cos \phi) \quad \text{and} \quad - W_p \sin \phi.$$

Hence the generalized force on the coördinate θ, is

$$- \frac{dV}{d\theta} + W_p(K_{y\theta} - (u - g)K_{\phi\theta} \cos \phi) - RK_{x\theta}$$

and the generalized force on the relative coördinate U, is

$$P - W_p \sin \phi.$$

The velocity components of the projectile are

$$\dot{u} - \dot{x}_g \cos \phi - \dot{y}_g \sin \phi$$

$$\dot{x}_y \sin \phi - \dot{y}_g \cos \phi + (u - g)\dot{\phi}$$

so that the kinetic energy of the total system is

$$T = \tfrac{1}{2}A\dot{\theta}^2 + \tfrac{1}{2}m_p[(\dot{u} - \dot{x}_g \cos \phi + \dot{y}_g \sin \phi)^2 + ((\dot{x}_g \sin \phi - \dot{y}_g \cos \phi) + (u - g)\dot{\phi})^2]$$

or in terms of the velocity ratios of the recoiling parts,

$$T = \tfrac{1}{2}A\dot{\theta}^2 + \tfrac{1}{2}m_p[\dot{u}^2 - 2\dot{u}(K_{x\theta} \cos \phi + K_{y\theta} \sin \phi)\dot{\theta} + (K_{x\theta}^2 + K_{y\theta}^2 + 2(u - g)(K_{x\theta} \sin \phi - K_{x\theta} \cos \phi)K_{\phi\theta} + (u - g)^2 K_{\phi\theta}^2)\dot{\theta}^2].$$

The Lagrangian equations of motion are

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}}\right) - \frac{\partial T}{\partial \theta} = - \frac{\partial V}{\partial \theta} - RK_{x\theta} + W_p(K_{y\theta} - (u - g)K_{\phi\theta} \cos \phi)$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{u}}\right) - \frac{\partial T}{\partial u} = P - W_p \sin \phi.$$

Performing the differentiations,

$$[A + m_p(K_{x\theta}^2 + K_{y\theta}^2 + 2(u - g)K_{\phi\theta}(K_{x\theta}\sin\phi - K_{y\theta}\cos\phi) + (u - g)^2K_{\phi\theta}^2]\ddot{\theta} - m_p(K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)\ddot{u} + 2m_p(u - g)K_{\phi\theta}^2\dot{u}\dot{\theta} + \left[\frac{1}{2}\frac{\partial A}{\partial\theta} + m_p\left(K_{x\theta}\frac{dK_{x\theta}}{d\theta} + K_{y\theta}\frac{dK_{y\theta}}{d\theta} + (u - g)\frac{dK_{\phi\theta}}{d\theta}(K_{x\theta}\sin\phi - K_{y\theta}\cos\phi) + (u - g)K_{\phi\theta}\left(\frac{dK_{x\theta}}{d\theta}\sin\phi - \frac{dK_{y\theta}}{d\theta}\cos\phi\right) + (u - g)K_{\phi\theta}^2(K_{x\theta}\cos\phi + K_{y\theta}\sin\phi) + (u - g)^2K_{\phi\theta}\frac{dK_{\phi\theta}}{d\theta}\right)\right]\dot{\theta}^2 = -\frac{dV}{d\theta} - RK_{x\theta} + W_p(K_{y\theta} - (u - g)K_{\phi\theta}\cos\phi)$$

and

$$m_p\left[\ddot{u} - (K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)\ddot{\theta} - \left(\frac{dK_{x\theta}}{d\theta}\cos\phi + \frac{dK_{y\theta}}{d\theta}\sin\phi - (u - g)K_{\phi\theta}^2\right)\dot{\theta}^2\right] = P - W_p\sin\phi,$$

where the velocity ratios and their derivations are obtained from the previous kinematic procedure.

Since the powder pressure period is of a very short time duration, we may omit the velocity terms and all finite forces in comparison with the powder pressure force, as well as changes in the configuration, so that the velocity ratios are nearly constant.

Therefore, for a close approximation,

$$[A + m_p(K_{x\theta}^2 + K_{y\theta}^2 + 2(u - g)K_{\phi\theta}(K_{x\theta}\sin\phi - K_{y\theta}\cos\phi) + (u - g)^2K_{\phi\theta}^2)]\ddot{\theta} - m_p(K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)\ddot{u} = 0$$

and

$$m_p\ddot{u} - (K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)\ddot{\theta} = P.$$

The relation of the displacements during the travel of the projectile up the bore is

$$\Delta\theta = \frac{m_p(K_{x\theta\theta}\cos\phi + K_{y\theta\theta}\sin\phi)u}{A + m_p(K_{x\theta\theta}^2 + K_{y\theta\theta}^2 + 2(u-g)K_{\phi\theta}(K_{x\theta\theta}\sin\phi - K_{y\theta\theta}\cos\phi) + (u-g)^2K_{\phi\theta}^2)}$$

or approximately

$$\Delta\theta = \frac{m_p(K_{x\theta\theta}\cos\phi + K_{y\theta\theta}\sin\phi)u}{A},$$

where $A = \sum m_s K_{s\theta}^2$ for the recoiling parts.

To obtain the lateral reaction N of the gun on the projectile we must consider the lateral acceleration of the projectile.

The acceleration is compounded with the acceleration of the trunnions B, i.e. $\ddot{x}_g$ and $\ddot{y}_g$, the lateral acceleration of the gun $(u-g)\ddot{\phi}$ at P, and the coriolis component $2\dot{u}\dot{\phi}$, the centripetal acceleration $(u-g)\dot{\phi}^2$ being along the bore and thus having no effect. The equation of motion is

$m_p(\ddot{x}_g\sin\phi - \ddot{y}_g\cos\phi + (u-g)\ddot{\phi} + 2\dot{u}\dot{\phi}) = N - W_p\cos\phi$.

Since,

$$\ddot{x}_g = K_{x\theta\theta}\ddot{\theta} + \frac{dK_{x\theta\theta}}{d\theta}\dot{\theta}^2,$$

$$\ddot{y}_g = K_{y\theta\theta}\cdot\ddot{\theta} + \frac{dK_{y\theta\theta}}{d\theta}\dot{\theta}^2 \quad \text{and} \quad \dot{\phi} = K_{\phi\theta}\cdot\dot{\theta},$$

$$\ddot{\phi} = K_{\phi\theta}\ddot{\theta} + \frac{dK_{\phi\theta}}{d\theta}\dot{\theta}^2,$$

we have, on substituting,

$$N - W_p\cos\phi = m_p[(K_{x\theta\theta}\sin\phi - K_{y\theta\theta}\cos\phi + (u-g)K_{\phi\theta})\ddot{\theta} + \left(\frac{dK_{x\theta\theta}}{d\theta}\sin\phi - \frac{dK_{y\theta\theta}}{d\theta}\cos\phi + (u-g)\frac{dK_{\phi\theta}}{d\theta}\right)\dot{\theta}^2 + 2K_{\phi\theta}\dot{u}\dot{\theta}.$$

Again, a good approximation is

$$N = m_p(K_{x\theta\theta}\sin\phi - K_{y\theta\theta}\cos\phi + (u-g)K_{\phi\theta})\ddot{\theta}.$$

An interesting ballistic procedure serves as a check as well as a simplification of the previous analysis. Due to the very short time period of the powder reaction, we may consider the momentum generated by the impulsive action

of the powder pressure. For such cases, we omit the short time action of finite forces such as the weights and recoil resistances. Moreover, we are only concerned with the velocity ratios alone, since the rate of change of the configuration of the system is small. Due to the lateral lift and angular whip of the gun, however, we must also include the lateral impulse upon the projectile and its reaction on the gun.

Let (Fig. 53)

$P_t = \int P dt$ = Impulsive reaction of the powder pressure along the axis of the bore.

$N_t = \int N dt$ = Impulsive lateral reaction between the gun and projectile.

The equations of momentum for the projectile are,

$$P_t = m_p[\dot{u} - (\dot{x}_g \cos\phi + \dot{y}_g \sin\phi)],$$
$$N_t = m_p[(u - g)\dot{\phi} + (\dot{x}_g \sin\phi - \dot{y}_g \cos\phi)].$$

In terms of the velocity ratios of the recoiling parts,

$$P_t = m_p[\dot{u} - (K_{x\theta} \cos\phi + K_{y\theta} \sin\phi)\dot{\theta}],$$
$$N_t = m_p[(u - g)K_{\phi\theta} + (K_{x\theta} \sin\phi - K_{y\theta} \cos\phi)]\dot{\theta}.$$

For the momentum generated in the gun recoil mechanism we must consider the generalized impulsive reactions reduced to the coördinate θ.

The finite differential work of the powder reaction is

$$P(\dot{x}_g \cos\phi + \dot{y}_g \sin\phi)dt = P(K_{x\theta} \cos\phi + K_{y\theta} \sin\phi)d\theta$$

and similarly for the lateral reaction,

$$-N[(u - g)\dot{\phi} + \dot{x}_g \sin\phi - \dot{y}_g \cos\phi]dt$$
$$= -N[(u - g)K_{\phi\theta} + (K_{x\theta} \sin\phi - K_{y\theta} \cos\phi)]d\theta,$$

so that the generalized impulsive reactions reduced to the coördinate θ are

$$P_t(K_{x\theta} \cos\phi + K_{y\theta} \sin\phi)$$
$$- N_t[(u - g)K_{\phi\theta} + (K_{x\theta} \sin\phi - K_{y\theta} \cos\phi)].$$

The equation of momentum for the gun recoiling parts is

$$A\dot{\theta} = P_t(K_{x\theta} \cos\phi + K_{y\theta} \sin\phi) - [(u - g)K_{\phi\theta}$$
$$+ N_t(K_{x\theta} \sin\phi - K_{y\theta} \cos\phi)].$$

Substituting P_t and N_t from the momentum equations of the projectile, we have

$$A\ddot{\theta} = m_p(K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)(\dot{u} - (K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)\dot{\theta}) - ((u-g)K_{\phi\theta} + (K_{x\theta}\sin\phi - K_{y\theta}\cos\phi))^2\dot{\theta}$$

$$\therefore \quad [A + m_p(K_{x\theta}^2 + K_{y\theta}^2 + (u-g)^2K_{\phi\theta}^2 + 2(u-g)K_{\phi\theta}(K_{x\theta}\sin\phi - K_{y\theta}\cos\phi))]\dot{\theta} = m_p(K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)\dot{u}.$$

Integrating, we have for the relation of the displacements in terms of the travel up the bore given by

$$\Delta\theta = \frac{m_p(K_{x\theta}\cos\phi + K_{y\theta}\sin\phi)u}{A + m_p(K_{x\theta}^2 + K_{y\theta}^2 + (u-g)^2K_{\phi\theta}^2 + 2(u-g)K_{\phi\theta}(K_{x\theta}\sin\phi - K_{y\theta}\cos\phi))},$$

where the velocity ratios are obtained from the previous kinematic analysis of the gun carriage mechanism. We note this expression agrees with that obtained from the first approximation of the more exact theory.

(*To be continued*)

Vacuum Levers. H. L. BROSE AND J. E. KEYSTON. (*Jour. Scient. Instr.*, Jan., 1930.) It is sometimes necessary to produce motions within a vacuum by manipulations performed on the outside. Two ways of doing this have been available. A ground joint of glass, quartz or metal has permitted rotary motion. The disadvantages are the restriction of the motion, the careful manipulation necessary with heavy apparatus and the escape of vapor from the lubricating grease into the vacuum. The second method depends on the displacement of an iron object inside the vacuum by a magnet on the outside. This is very limited in its range.

The authors describe a third method. A rod of metal of suitable shape projects into the vacuum. It runs through a metal cap to which it is soldered. The cap in turn is soldered so as to close the end of a flexible corrugated brass tube. This is soldered to a copper tube that is welded to a glass tube that leads into the vacuum space. By bending the flexible tube the rod extending into the vacuum can be moved about and with two such arrangements the operator has two crude fingers by which he can produce changes within the space. The following purposes may thus be served: adjustment of spark gaps, cutting soft substances, scraping surfaces, adjusting mirrors and rubbing surfaces in vacuo. The flexible tube stands bending through as much as 90°.

G. F. S.

COMMITTEE ON SCIENCE AND THE ARTS.

ABSTRACTS OF REPORTS.

INVENTIONS OF DR. ELMER A. SPERRY BASED ON THE GYROSCOPE.

HALL OF THE INSTITUTE,
PHILADELPHIA, March 6, 1929.

No. 2896.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the inventions of Doctor Elmer A. Sperry, of Brooklyn, New York, based on the Gyroscope, reports as follows:

For his invention of the Gyro-Compass Doctor Elmer A. Sperry received the award of the John Scott Medal from The Franklin Institute, September, 1914. Since that time Doctor Sperry has invented and put intro practical use the following instruments: (1) A Gyro-Pilot which automatically steers a vessel upon a prescribed course; (2) a Gyro-Stabilizer which largely eliminates a vessel's roll; (3) a Gyro-Roll and Pitch Recorder which permits a comparison to be made between the motion of a vessel with and without the stabilizer; (4) a Gyro Track Recorder which enables the irregularities in a railroad track to be located and measured. Together with the gyro-compass, these instruments constitute a group of five inventions the operation of which depends in each case upon the fundamental principles which govern the behavior of a gyroscope. Hence it has been deemed suitable to consider the recommendation of some award to Doctor Sperry for the invention of these instruments as a group.

1. *The Gyro-Compass.*—The prior art of using the indications of a magnetic compass to steer by has not proved satisfactory because the magnetic poles of the earth do not coincide with the geographical poles and are subject to a slow but continuous movement. As a result, the magnetic needle

points to the true north only along an irregular line which, in this hemisphere, runs from North Carolina to Lake Superior. This is called the agonic line or line of no declination. At places to the east of this line the needle points to the west of north while at places to the west of the line it points to the east of north. The fact that the declination slowly changes from year to year is an additional complication. The agonic line is now moving westward, the declination of places east of the line increasing and that of places west of the line decreasing. This change is called the variation; this annual variation at Philadelphia being about four minutes while its declination is about seven degrees, thirty minutes, west.

In order to provide a compass that will indicate the true north at any position on the surface of the earth, Doctor Sperry invented the Gyro-Compass that has proved to be of great value in navigation. This instrument is based on the fact that a spinning mass of matter or gyroscope, when mounted on a universal bearing, and carried along a circular path, turns itself so that its own axis of spin is parallel with the axis of the circle and perpendicular to its plane. Thus the spinning wheel of the Gyro-Compass automatically tilts its own axis of spin into parallelism with the earth's polar axis and maintains this direction fixed in space however the supporting frame may be tilted.

In the Sperry Gyro-Compass the Gyro wheel is universally mounted and a mercury U-tube is fixed to its frame in such a manner that the spinning axis shall always point to the true north whatever may be its position on the surface of the earth.

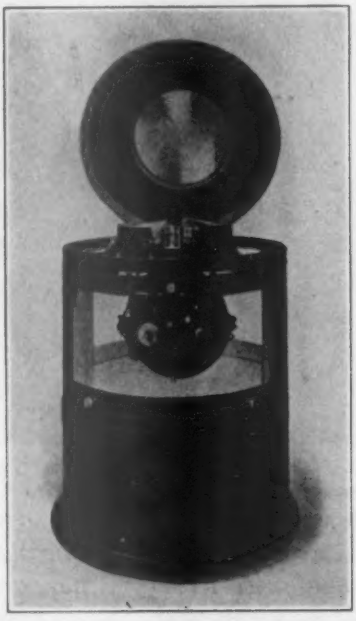
2. *The Gyro-Pilot.*—The Gyro-Pilot is an automatic device used to steer ships without the attention of a quartermaster at the wheel and also to enable the ship to be driven in a straighter course, resulting in a saving of time and power.

In the practical steering of a ship there is a certain amount of time lost between the observation of any change in the direction of the ship as indicated by the reading of the compass and the operation of the rudder required to bring it back upon its course.

The deviation of a ship from its prescribed course is called its *yaw* and the main use of the rudder is to overcome it.

Beside the time lost in hand steering there is the tendency to overdo the correction and with so great a mass as a ship its inertia, when once the correction is begun, will carry it beyond the amount of correction required to bring it back to its course, and this must be overcome by an opposite shift of the rudder. The Gyro-Pilot has been developed to overcome these disadvantages. It is intended for use primarily with the Gyro-Compass, Plate I. Its reliability depends

PLATE I



upon that of the Gyro wheel which weighs 55 pounds, is mounted on an armature shaft and has a speed of 6000 R.P.M. or 100 per second.

The aluminium casing in which the wheel is contained is supported on horizontal bearings within a vertical ring which is itself suspended from the compass head by strands of fine piano wire. This arrangement constitutes the universal bearing that is required in a gyroscope.

In addition to the Gyro-Compass, the Gyro-Pilot makes use of a repeater compass connected to the master compass

by a conducting cable and mounted on a support near the steering wheel. This support and its connections are shown in Plate II, while Plate III shows its connection to the steering wheel.

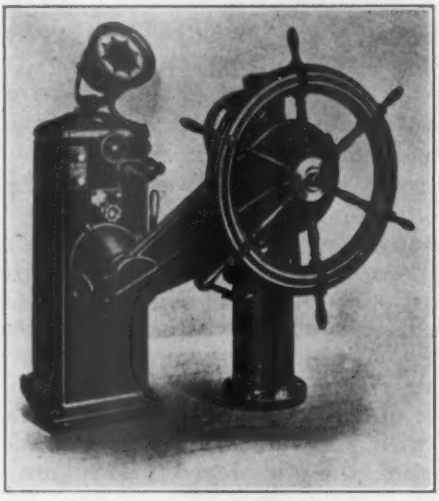
PLATE II

In order to preserve the results obtained with the Gyro-Pilot, use is made of a course recorder which is another form of repeater compass, which combined with a clockwork that moves a continuous strip of paper, makes a graphic record of the time and courses steered. With this apparatus it is possible to compare the results when the course is hand steered from the readings of a magnetic compass, from a Gyro-Compass, or when automatically steered by the Gyro-Pilot.

The results obtained by each of these methods of steering are shown in Plate IV. The average yaw when steered by hand from the magnetic compass is from 20 to 21 degrees, when steered by hand from the Gyro-Compass, 5–9 degrees, and when steered automatically by the Gyro-Pilot, only two degrees.

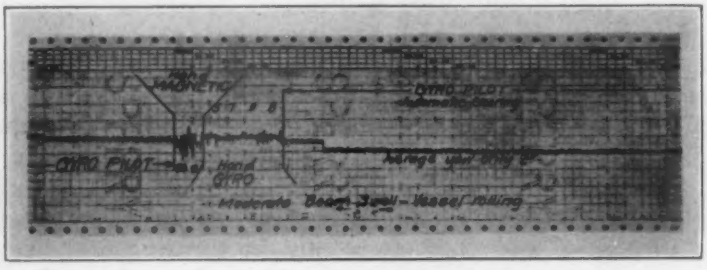
The cutting down of the departure of the ship from its course, by the use of the Gyro-Pilot results in a great saving in the power required to keep it on this course and reduces the loss of time for the purpose.

PLATE III



The fundamental patent for the Gyro-Pilot was granted to Elmer A. Sperry on November 30, 1920 on an application filed November 30, 1914.

PLATE IV



The type of azimuth indicator used with the master controller differs from the gyro-compass in that it has no

directive force and will remain in any position in which it is set.

In order to secure this result, two rotors, rotating in opposite directions are used. The casings in which the rotors are suspended are connected in such a way that precession is permitted in opposite directions only. This overcomes the error resulting from the earth's rotation, since the tendency to change the direction of the axis of one gyro is overcome by an equal and opposite tendency in the other.

Arrangements are provided for contacts by means of which the motors controlling the rudder are automatically started and stopped as required.

In the United States patent twenty-six claims are granted, the twelfth and nineteenth being as follows:

12. "In a steering apparatus for dirigible craft, a course indicator adapted to be set at will, automatic means controlled by said indicator for keeping the craft on its general course and means associated with said aforementioned means for preventing the yawing of the craft."

19. "In steering apparatus, an azimuth indicator, a settable course governing device including a member having a connection with said indicator, an independently movable member adjacent thereto, a steering engine controlled by the relative movements of said members, and a follow-up connection between said engine and said second member."

While but a single patent has been issued in the United States a number of applications covering improvements are pending. Many claims have been allowed on these applications which are similar to claims already granted in British patents issued in the name of Elmer A. Sperry, Jr.

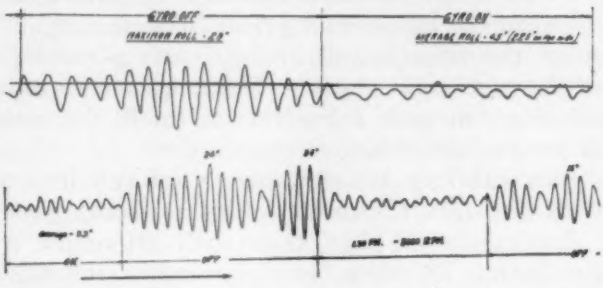
The Sperry Gyro-Pilot has come into extensive use on ships of various sizes ranging from yachts to the largest passenger ships such as the Leviathan. Reports from the navigators of these vessels indicate that its use has been most satisfactory.

3. *The Gyro-Stabilizer.*—This invention has an extensive application, being used on battleships, ocean liners, yachts and airplanes, and is most helpful in securing stability in these various types of ships.

The result of the use of the stabilizer is shown in Plate V. It is evident, from an inspection of this plate, that the use

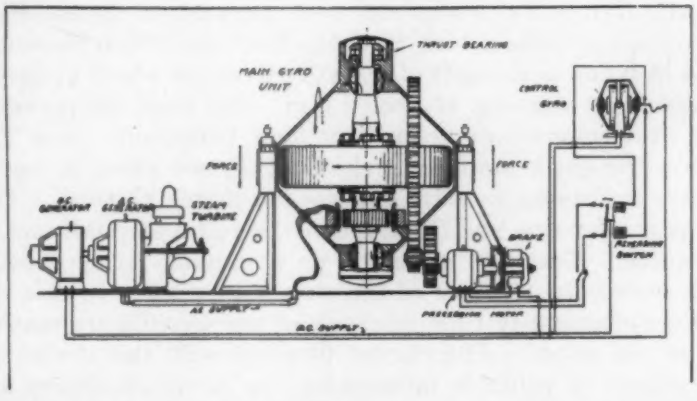
of a gyro-stabilizer greatly reduces the roll of a ship and would add much to the comfort of those on board.

PLATE V



A diagram of the equipment of the gyro-stabilizer is shown in Plate VI in which the different parts of the unit are indicated.

PLATE VI



The weight of the main gyro unit depends upon the weight of the ship in which it is to be installed, usually less than one per cent. of the ship's displacement, but its purpose is in every case to oppose by its precessional motion any force tending to cause the ship to roll. This gyro wheel is run by an alternating current squirrel cage motor at a high rate of speed and, aside from needing a considerable supply of oil for lubrication, requires little or no attention. To

avoid air friction it is inclosed in an air tight case in which there is a partial vacuum. The maximum roll at any time is due to the sum of the minor rolls caused by blows given the ship by the waves, and since the gyro-stabilizer opposes each blow as it is given, the resultant roll is almost nothing.

The function of the control gyro is to detect the slightest tendency of the ship to roll and to close a switch in the circuit of the precession motor. This releases the brake and starts the motor in such a direction as to tilt the main gyro and thus prevent the rolling of the ship.

The gyro-stabilizer has abundantly proved its value on ships of various sizes, the results of its use being: prevention of roll; elimination of bilge keels with attendant friction; ability to maintain its course in rough weather; the elimination of wallowing which reduces the speed and is expensive in power; ease of navigation when the weather is rough; reduction of stresses in the ship and its machinery; and strain upon the engine.

4. *Roll and Pitch Recorder.*—The curves already shown as records of the roll of a ship both with and without the stabilizer have been obtained with the ship Roll and Pitch Recorder. This instrument consists of a small gyroscope wheel $5\frac{1}{4}$ inches in diameter, running at 6000 r.p.m.; and since its period is long it is equivalent to a very long pendulum. For this reason the quick motions of the boat do not affect it, and it always maintains its axis very close to a true vertical. This forms a reference line from which the roll and pitch can be measured. Tracings are made on a moving strip of paper that record the motions of the ship with respect to this line and simultaneously time intervals of ten seconds are marked off on the paper. The curves obtained with this device are the source of valuable information for naval architects and ship captains.

5. *The Gyro Track Recorder.*—This is an automatically recording device used to locate and measure the uneven spots and irregularities in a railroad track. The gyroscope is small, and when mounted in a car will hold its position of rotation irrespective of the rocking of the car, and consequently can be used to register on a traveling sheet any variation in the height of the rails from a horizontal position.

This device will make an accurate record of the tilt of the car, track elevation, time and distance traveled, gauge of the track, defects in rail joints, the depressions of the rail due to the weight of the car and in fact all details concerning the track except flaws in the material of the rail.

In consideration of his application of the principle of the gyroscope to the development of means whereby vessels may be navigated with greater safety, comfort, and economy, both in time and fuel, and whereby the irregularity of movement of vessels and trains may be accurately recorded THE FRANKLIN INSTITUTE awards its ELLIOTT CRESSON MEDAL to DOCTOR ELMER A. SPERRY, of Brooklyn, New York.

The Variation of the Dielectric Constants of Some Organic Liquids with Frequency in the Range 1 to 1000 Kilocycles. R. W. LUNT and M. A. G. RAU. (*Proc. Roy. Soc.*, A 801.) It is known that the dielectric constant of liquids changes in accordance with Debye's theory for frequencies from 10^4 to 10^5 kilocycles per sec., but very little is known concerning the variation of this property at frequencies below 10^3 kc. In this paper several organic liquids were examined and their dielectric constants, in some cases also their electrical resistances, measured. Within the limits of experimental error benzene, ether, methylated ether and chloroform show no change in dielectric constant in the frequency range 1 to 10^3 kc. The same holds true for aniline, nitrobenzene, ethyl alcohol and acetone for the range 1 to 10^2 kc., while for higher frequencies there is in each case a small increase.

The course followed by the electric conductivity of aniline is interesting. Up to 10^2 kc. it diminishes slowly, then the rate is accelerated and at 10^3 kc. it was too small to be measured on the apparatus. The conductivity of acetone and ethyl alcohol was not found to change, but that of nitrobenzene diminished though more slowly than in the case of aniline.

G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

RELATION BETWEEN THE INTERNATIONAL AND MECHANICAL WATTS.

In many precise heat measurements now being made the international joule is used as the energy unit. As outlined in Technical News Bulletin No. 152 (December, 1929) replacement of the present international units by absolute units is in prospect, and this change may become effective within a few years. For many purposes data expressed in mechanical joules are more useful than those expressed in the arbitrary international unit, and the prospective abandonment of the present international electrical units adds to the advantages of expressing results in absolute or mechanical joules.

To reduce results obtained in international joules to their equivalent values in mechanical joules, a conversion factor is needed. In Bureau of Standards Circular No. 60, second edition issued in 1920, it is stated that one international watt = 1.00034 mechanical watts.

The ratio published in 1920 is subject to revision in the light of later evidence. The provisional value for the conversion factor given in this note is intended to serve until a more authoritative figure becomes available.

It is desirable in the first place to make it clear that the "International Units" as maintained at the different national laboratories are not exactly the same, and precise conversion factors for changing from the "International" to absolute units will therefore be slightly different in different countries. The existing differences in the values of the international ohm and volt are however only a few parts in 100,000, so that differences of perhaps 1 in 10,000 may exist in the international watt derived from standards maintained by the various national laboratories. A difference of this magnitude is not however of major importance in heat measurements.

The International Committee on Weights and Measures at its meeting of June, 1929, definitely accepted the principle of

* Communicated by the Director.

using absolute electrical units. It made no attempt, however, to fix the ratios between those units and the international ones as at present maintained. This problem and the procedure to be followed in making the transition are referred to the Advisory Committee on Electricity for recommendations.

New determinations of the absolute units are in progress at several laboratories. Presumably the procedure which will be followed in introducing the new units will consist essentially of four steps. First, the results of the new determinations as represented by physical standards (resistance coils and standard cells) will be compared among the several laboratories, and agreement will be reached on a best absolute value for certain groups of standards. Second, through comparisons with some of these groups each national laboratory will determine precisely what the conversion factors should be to change over from its present units to the new ones. Third, these conversion factors will be announced, and for a certain period the national laboratories will give values on both bases in certifying standards. Finally, all values will be given only in the new absolute units.

Incidentally it may be remarked that systematic methods will be adopted to prevent future divergences between countries. If any further adjustment of units should become necessary it will be made only by international action and should be the same in all countries.

It will require some time before the above procedure can be carried through, since it involves completion of several experimental determinations and adjustment of possible discrepancies in the results. Up to the present time progress in the negotiations has been surprisingly rapid. Some members of the International Advisory Committee have thought that the change in units might be made in two years. It appears not impossible that the necessary agreements on values may be completed in time for formal ratification at the General Conference on Weights and Measures which convenes in 1933, so that the new units would be introduced into general use during the following year.

To fix the values of the units to the sixth figure will be difficult, but experimental data already available are sufficient to justify a prediction to the fifth. There are several

lines of evidence indicating that the standards as established in 1910 have not drifted in value by many parts in 100,000, so that all good absolute measurements made since then are still significant.

For the ohm there are three determinations all indicating that the international ohm is too large by 5 parts in 10,000. For the standard cell absolute values are somewhat less certain. Current balance measurements at the Bureau of Standards reported in 1913 would give 1.01872 volts, and those made at the British National Physical Laboratory at about that time would indicate about 1.01868, but recent unpublished measurements at the bureau give about 1.01877. Assuming that this more nearly represents the *present American* units, and taking 1.01875 volts as an approximation to the exact value one may say that probably our volt is too large by about 45 parts in 100,000. That is, the cell is assigned a value of 1.01830 when it should be 1.01875.

In the actual measurement of the joule or the watt the value of the volt enters as the square, since the relation

$$P = \frac{E^2}{R}$$

is used. Consequently the international joule is too large by about 4 parts in 10,000. The estimate of four may be slightly large; in fact the earlier determinations give a value somewhat nearer 3 in 10,000, but it would be surprising if final values went outside of this range.

Accordingly, it is recommended, upon the basis of data available to the Bureau of Standards, that in conversions involving international watts and mechanical watts the relation used be:

1 international watt = 1.0004 mechanical watts

From data now available it is to be expected that the figure given will not differ from any which may be officially adopted later, by more than 1 in 10,000.

RADIO ECHO SIGNAL RESEARCH.

A major purpose in the study of radio wave phenomena carried on by the bureau is to understand more completely

what happens to the radio waves between the transmitting and the receiving stations. It is well known that part of the radiation from the transmitting station reaches the upper atmosphere, from which it may be refracted back to earth. It is this refraction that makes possible long-distance communication.

In order to determine some of the properties of the upper atmosphere which are responsible for this phenomenon, the bureau and a number of other laboratories are coöperating in a study of echo signals. The procedure in this study is to record, by means of an oscillograph, the received signals from a powerful transmitter which is sending out pulses of extremely short duration. The oscillograph record shows for each pulse sent out, a sharp peak for the wave coming along the surface of the earth, followed at a measurable time later by one or more peaks representing "echos" from the upper atmosphere. By measuring on the oscillogram the interval of time between the reception of the ground wave and the sky wave, it is possible by simple calculation to determine the apparent height in the atmosphere which the wave reached. In this method of calculation it is assumed that reflection takes place from an ionized layer in the upper atmosphere. Actual reflection as from a mirror does not take place, but a gradual bending or refraction occurs, due to an increase of ionization with height, so that the actual height reached by the wave is somewhat less than that given by the calculation.

At present, pulse signals are being sent at regular intervals from station NKF of the Naval Research Laboratory at Bellevue, D. C., and are being received and oscillographed at the Bureau of Standards field station near Kensington, Md. Records obtained since the first of the year show that, on 4045 kilocycles, the sky wave arrives at the receiving station on the average 0.00143 second later than the ground wave, at 11:30 A.M. on normal days, while the retardation for the same frequency at 4:00 P.M. averages 0.00150 second. These retardations correspond to 225 km. and 235 km., respectively, as the apparent height of the ionized layer.

With the frequency of 8650 kc, the average retardation is 0.00184 second at 11:30 A.M. and 0.00186 second at 4 P.M., corresponding to apparent heights of 287 km. and 290 km., re-

spectively. The greater retardations for the higher frequencies may be attributed to dispersion. As with light waves, the index of refraction is thus shown to increase with frequency.

The retardations are shown to increase after sunset to values as high as 0.003 second for 4045 kc. At sunrise they return abruptly to normal daytime values. Records obtained at 4:00 P.M. on March 13, 1930, during a magnetic storm, show retardations of 0.00162 second for 4045 kc, and 0.00285 second for 8650 kc, as compared with the normal values of 0.00150 second and 0.00186 second, respectively.

It is planned to extend the study to other frequencies, in order to understand more completely the distribution of ionization, and to continue the observations over a considerable period of time so that seasonal variations may be studied.

TESTS OF AIRPLANE ANTENNAS.

The bureau is conducting a research on receiving antennas for airplane use. As a result of preliminary work done in 1928 the vertical pole antenna was developed, and there is still every indication that it is the preferable type of antenna for reception on airplnes. Some difficulties have occurred in its use, however, which justify renewed study of the antenna problem directed both to removing these difficulties and to a more careful study of the possibilities of the several available types of antennas. The accumulation of ice on the vertical pole antenna encountered under certain weather conditions is a serious problem. In some cases this ice accumulation cuts down the signal markedly and also sets up vibrations which may be so severe as to break off the antenna or to endanger the airplane. A number of expedients are in view to eliminate these difficulties.

Some tests have been begun of the various possible types of fixed antennas. In addition to the vertical pole, these include a short longitudinal inclined antenna, the longitudinal horizontal antenna, transverse L antenna, transverse T antenna, a transverse horizontal di-pole antenna, a wing-tipped T antenna, and combinations of these. These are being studied for their sensitivity, directional errors, and localizing effect (when over the beacon tower). The longitudinal inclined antenna,

transverse T antenna, and wing-tipped T antenna give localizing effects which may be quite as useful as that obtained with the vertical pole antenna; these types, however, introduce errors in course indication which are due to the inclination of the antenna with respect to the course when the orientation of the airplane is shifted, and may be very large when within five or ten miles of the beacon station. These preliminary results will be extended and more complete data obtained on the several types of antennas.

AIRPLANE DIRECTION FINDERS.

One of the lines of aeronautic radio research work carried on by the bureau is the development of a direction finder for use aboard airplanes. Such a device is inherently more difficult for the pilot to operate than the radio range beacon aids. It, however, offers a means of navigation for the itinerant airplane or for any aircraft regardless of whether or not it follows one of the established airways. It thus supplements the Department's radio range beacon system. A direction finder of the rotating-coil type is being developed, of maximum simplicity in use, usable either as a homing device or for bearing indications. A model has been constructed and is now under laboratory test which is expected to fulfill these requirements. Flight tests on this direction finder will begin as soon as it is thoroughly tested in the laboratory.

This direction finder employs two small crossed loop antennas rotating as a unit. An antenna tuning system has been devised, permitting a uni-tuning control and proper combinations of the two antenna currents without mechanical switching in the radio-frequency circuits. It operates on the comparison of two signals rather than on zero signal. Hence it permits of specially advantageous operation under conditions of atmospheric or external interference, and when used as a homing device gives a positive indication of the direction of deviation from the course. It also offers an adjustment whereby the course indications may be made as sharp as is desired.

Course indications may be either aural or visual. The aural indications may consist of the comparison of the inten-

sities of two signals, or these signals may be interlocked giving the same course indications as in the aural radio range beacon system. Visual indication may be obtained by the use of a zero-center deflection instrument. With either type of course indication, bearings may be obtained from any transmitting station within the frequency range of the device. Means are also being worked out whereby a vibrating-reed indicator gives the indications, thereby taking advantage of the freedom from interference inherent in this type of indication.

The research work on this development is actively in progress, and is expected to include flight tests of various types of direction finders.

THE SPECTRA OF LUTECIUM.

A paper entitled "Regularities in the Spectra of Lutecium" has been prepared and will be published later in the *Bureau of Standards Journal of Research*. This is based on new observations of wave-lengths and relative intensities of spectral lines characterizing lutecium atoms in successive stages of ionization. The lines were separated into 3 groups, the Lu_I spectrum of neutral atoms, the Lu_{II} spectrum of Lu^+ atoms and the Lu_{III} spectrum of Lu^{++} atoms. Regularities were discovered in each of the three spectra and practically all of the stronger lines have been explained as combinations of identified spectral terms. These spectral terms represent atomic energies and are associated with electron configurations in the atoms. The normal state of neutral Lu atoms is represented by a ^2D spectral term, that of Lu^+ atoms by a ^1S term and that of Lu^{++} by ^2S. This analysis shows that the spectra are produced by electrons in s, d, and p orbits only; the electrons in f orbits assumed to be present in the rare earth elements form a stable closed shell when 14 of this type are grouped in lutecium atoms and, therefore, contribute nothing to the optical spectra. The spectra of lutecium are the first of any of the 14 rare earth elements to succumb to this method of analysis which gives information on atomic structure. In order to identify ytterbium lines which appeared as impurities in the lutecium spectra it has been necessary to photograph the former also.

SEPARATION AND DETERMINATION OF OSMIUM AND RUTHENIUM.

During March, the bureau made a number of observations dealing with the separation and determination of osmium and ruthenium. It was found that osmium apparently can be quantitatively separated from all of the other platinum metals by distillation with nitric acid and that it can also be quantitatively separated from ruthenium by distillation with sulphuric acid at a temperature approaching the boiling point of the acid. If a chlorate is added to the sulphuric acid solution ruthenium can also be quantitatively distilled, thus offering a probable means of separating osmium and ruthenium together from iridium or other platinum metals which can then be followed by a separation of osmium from ruthenium by distillation with sulphuric acid alone. Further use of 6 *N* hydrocholoric acid saturated with sulphur dioxide indicates that it is a satisfactory absorbing solution for both osmium and ruthenium. However, small losses of osmium were still found to occur in spite of the use of a newly designed set of receiving flasks. This loss may possibly occur during the evaporation of a solution, or during the precipitation of osmium dioxide by hydrolysis. The cause of this loss will have to be discovered and eliminated before the use of this method for the determination of osmium can be regarded as satisfactory.

FILTERS FOR CHANGING THE COLOR TEMPERATURE OF INCANDESCENT SOURCES TO MEAN SUNLIGHT.

The bureau has received a memorandum from the National Illumination Committee of Great Britain, Sub-Committee on Colorimetry, prepared by Mr. J. Guild and entitled "Standard Illuminant for Colorimetry." The following reference to the Davis-Gibson filters is taken from that memorandum.

> "The extensive series of filters developed by Messrs. Davis and Gibson have a value which is not measurable by the merits of any one of the filters for any one specific purpose. These filters provide a basis for tackling innumerable problems connected with the color tempera-

ture scale, and with heterochromatic photometry, which is far in advance, as regards completeness and experimental accuracy, of anything hitherto available. There is nothing else comparable with them for such purposes; and research workers on photometry and colorimetry will necessarily use these filters for a variety of purposes, and will become familiar with the technique of their construction and use."

Mr. Guild, therefore, believes that "the Committee ought to recommend a new standard employing filters from the Davis-Gibson series." He is also willing to use the value of 2848° K, likewise recommended in the Davis-Gibson memorandum, as the color temperature of the source for use with the "white-light" filter.

CAST IRON FOR ENAMELING PURPOSES.

Since the close of research work on his investigation, a report of which has appeared, or will appear, in the *Bureau of Standards Journal of Research*, the *Journal of the American Ceramic Society*, *Transactions of the American Foundrymen's Association*, and *Metals and Alloys*, samples of iron which gave serious trouble in regular production have been sent in from three plants, and have been studied with a view to determining the source of their blistering tendency. These samples, coming as they did directly from factories which were having trouble in actual production with the irons submitted, afforded an opportunity for the bureau to apply the findings of the investigation, and observe their efficacy. In the case of the first samples submitted, cross sections taken beneath the blistered areas and polished showed a spongy texture of the iron beneath. This condition is a mechanical cause of blistering, which was recognized and described in the report. The second sample submitted behaved in a rather peculiar manner when enameled. Chemical analysis showed it to contain only 1.2 per cent. silicon, which is such a low silicon content as to place it outside the range of typical enameling irons. It had been melted in an electric furnace (susceptible to superheating) and appeared to have an approximately eutectic composition, with an excessive amount of very finely divided free carbon,

which is believed to be readily oxidizable into the blister producing gas (mostly CO_2). There was, nevertheless, a narrow range of conditions under which this iron was enameled successfully. The recommendation made was to double, or more than double, the silicon content, and to eliminate the steel scrap being used in the charge, thus tending to avoid the eutectic composition. The third iron submitted was physically sound, and of more nearly typical chemical composition than the second. It was characterized as being the worst case of blistering iron which had come to the attention of the party submitting it. This iron behaved under enameling tests in practically the same manner as the iron which was studied in the investigation as representing a typical, severely blistering iron. When enameled under a variety of conditions it blistered strongly in most cases, but the preventatives which were described in the report proved quite effective. These included deep sandblasting and annealing as production measures, and machining as a laboratory test. The specimens from which the original surface had been thoroughly removed did not blister even when the ground coat was grossly overfired, a treatment which markedly accentuates any tendency to blistering.

The results obtained with these three irons thus fit in nicely with the findings of the investigation.

CHANGE IN VOLUME OF BURNED CLAY BODIES DURING USE.

The preceding news items on this investigation in Technical News Bulletins Nos. 146 and 153 (June, 1929 and January, 1930) covered the work conducted at the Columbus Branch on experimental bodies and individual clays. The work was supplemented at Washington by an investigation of commercial semivitreous ware representing 16 brands. The expansion of this ware, resulting from the adsorption of moisture, was measured by the interferometer method. It has been shown that a ceramic body which has undergone "adsorption expansion" will undergo an equivalent shrinkage when heated becase of the expulsion of adsorbed moisture. Tests on specimens taken from plates of five brands, and which had been stored in the laboratory for several months,

showed that from zero to 0.06 per cent. expansion had taken place. The plate which had apparently undergone no expansion had 2.0 per cent. absorption while the absorption of the four samples ranged from 9.4 to 12.5 per cent. Since the glaze on the plates was unbroken when the specimens were taken the results indicate that a slow expansion may take place in porous bodies in spite of a supposedly impervious coating of glaze. This would eventually result in crazing of the glaze, and, once the glaze was broken, the expansion of the body and resultant crazing could proceed with relative rapidity.

Specimens of each of the 16 brands of plates were also subjected to an autoclave treatment during which they were immersed in water under a pressure of 150 lbs./in^2. at approximately 182° C. for one hour. On removal from the cooled autoclave all of the specimens were badly crazed. Interferometer tests showed from 0.05 per cent. expansion for the body of 2.0 per cent. absorption to 0.14 per cent. expansion for a body of 11.0 per cent. absorption. As shown in the preceding news items, the composition may affect the relative expansion of a ceramic body as much, or more than, the porosity. Therefore, it is not surprising that the porosity-expansion relation shown by results on these 16 bodies is only very general, although it does indicate that expansion may be expected to increase with increased porosity.

STUDY OF FIRE-CLAYS.

The results obtained in this bureau's study of 26 representative fire-clays, reference to which was made in Technical News Bulletin No. 148 (August, 1929), will be published in full at an early date. Information included in the report relative to these clays covers:

1. Chemical analyses.
2. Tempering water and absorption of grog prepared from the clays.
3. Linear shrinkage and unfired strength.
4. Porosity of fired clay bodies.
5. Pyrometric cone equivalent values.
6. Linear thermal expansion.

7. Effect of temperature of firing on the mineralogical composition.
8. Moduli of elasticity and transverse strength of the fired clays.
9. Plastic flow.
10. Approximate location of the mines from which the clays were obtained, as well as a brief description of their geologic formation.

The chemical analyses of the clays show them to range from the aluminous type to the highly siliceous. The thermal expansions from 20° to 1000° C. of the fire-clays fired at 1155° and 1400° C. are given, and the clays classified into five groups according to their thermal expansion characteristics as determined by the free silica present either as quartz or in one or more of its allotropic modifications. The moduli of elasticity and transverse breaking strengths have been determined after receiving two different heat treatments and at several different temperatures.

The data obtained show that the thermal expansions of the fire-clays determined after firing at 1400° C. may be greater or less than after firing at 1155° C., depending entirely on the composition of the clays. Thermal expansion measurements and petrographic examinations given show the successive simultaneous development of cristobalite and mullite from the clays and finally the probable conversion of the cristobalite to a highly siliceous glass.

The moduli of elasticity and rupture of the clays are, with few exceptions, greater after firing at 1400° C. than after firing at 1155° C.

A comparison of the values for moduli of rupture and elasticity obtained at 550° C. with those obtained at atmospheric temperature shows in general that the percentage increase in moduli of elasticity and rupture is greater in highly siliceous clays than in aluminous clays. The plastic deflections of the clays, measured at 1000° C. are much lower for those fired at 1400° C. than those fired at 1155° C. and are also lower in the siliceous type of clays than in the aluminous.

COÖPERATIVE TESTS OF COATINGS FOR PIPE LINES.

On March 18 there was held in Tulsa, Okla., a conference called by the bureau to work out the details of an extensive test of protective coatings for pipe lines to be conducted jointly by the American Petroleum Institute, manufacturers of protective coatings, and the Bureau of Standards.

Twenty types of protective coatings will be applied to working oil lines in 15 locations chosen to include soil characteristics ranging from severely destructive to mildly destructive. The types of coatings will vary from greases, emulsions and enamels, to bituminous materials reinforced with or covered by woven fabric and metals.

Provisions have been made for testing on short lengths of pipe laid along-side these working lines as many other coatings as the manufacturers care to submit. The only requirements for this test are that the manufacturer furnish an identifying description of his product, apply it under inspection, and pay a testing fee intended to take care of most of that part of the expense of the test which is proportional to the number of specimens tested.

It is hoped that the application of the coatings to working lines will be started about June first. The short lengths of coated pipe will be buried at the time the line is protected.

CHART FOR DETERMINING THE HELIX ANGLES OF SCREW THREADS.

A chart issued by the Bureau of Standards during the past month shows graphically the relationships among diameters, leads, and helix angles of screw threads or other helical surfaces. This chart should prove of great value to mechanical engineers, since it furnishes a means for readily determining the helix angle at the major, pitch, or minor diameters or any of the standard pitches of the American National coarse, fine, hose coupling, pipe, and Acme threads as given in the 1928 Report of the National Screw Thread Commission. Usually, however, it is the helix angle corresponding to the pitch diameter which it is desirable to know.

The range of the chart includes diameters from 0.05 to 10 inches and 1 to 100 threads per inch. Diameters are represented by a vertical logarithmic scale, designated on each side

of the chart, and leads (or pitches of single-thread screws) on a horizontal logarithmic scale along the top. For convenient use of the chart, vertical lines are drawn corresponding to the threads per inch of the various standard systems and these are designated along the bottom of the chart. The abscissa for a non-standard pitch can be readily determined by interpolation on the lead scale and transferred to the diameter ordinate by means of a pair of dividers. The diagonal lines of the chart represent helix angles as designated.

Example. To determine the helix angle at the pitch line of a $1/2''$–20, 60° screw thread: The basic pitch diameter is .4675 inch. Reading opposite .468 on the diameter scale on the vertical line corresponding to 20 turns per inch, the diagonal line immediately below is 2° 0′ and interpolation gives the helix angle as 1° 57′.

There may be occasions, as in designing power transmission or conveying screws, when the helix angle would first be selected and a suitable corresponding combination of diameter and lead or pitch determined. Interesting comparisons of various standard screw thread systems can also be made by plotting them on the chart.

Copies of this chart, known as Miscellaneous Publication No. 109 of the Bureau of Standards, may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents per copy.

EXAMINATION OF OLD NEWSPAPERS.

Samples of old newspapers printed in this country and taken from the files of the New York Public Library, were examined in reference to their state of preservation. The papers were first graded jointly by three persons with consideration of color and strength. Five different grades were observed, therefore the best grade was designated No. 1 and the poorest grade No. 5, the others falling in order between these. The No. 1 papers were in excellent condition, having good color and strength. They showed little or no evidence of deterioration in any respect. The papers of No. 5 grade were badly deteriorated. They had a deep brown color and practically no strength, breaking with one fold.

After the papers were graded their fiber composition was determined and the appearance of their fibers noted.

Following are the fiber compositions of representative papers in the two extreme conditions, and the dates of issue of the papers:

Grade to which assigned.	Date of issue.	Condition.	Fiber composition.
			Per cent.
1	1872	Well preserved	Rag 20, Straw 80
1	1872	do	Esparto 100
1	1872	do	Esparto and Straw 90, Ground wood 10
1	1872	do	Rag 90, Esparto 10
1	1872	do	Rag 15, Chemical wood 15, Straw 70
5	1876	Badly deteriorated	Rag 50, Ground wood 50
5	1874	do	Rag 65, Straw 10, Ground wood 25
5	1877	do	Rag 75, Ground wood 25
5	1875	do	Rag 25, Ground wood 60, Straw 15
5	1875	do	Rag 30, Ground wood 70

Note.—Esparto is a grass used extensively abroad for paper making.

The complete results obtained will be published later in detail. They show the following interesting facts:

1. That while in the period covered by the samples, 1866–1880, a transition toward the use of ground wood fiber occurred, the modern type of newsprint paper composed of ground wood and unbleached sulphite fiber, and which is known to be impermanent, had not yet come into existence.

2. That all of the papers of the period 1866–1873 are in excellent condition, and are composed of fibers produced by chemical treatment from a wide variety of materials—rags, esparto grass, straw, and wood.

3. The papers issued during the period 1874–1880 showed more or less deterioration, and contained in most cases ground wood fiber, which is a crude fiber, mixed variously with the chemical fibers mentioned in (2).

All of which is further evidence that the degree of purification of the paper fiber is an important factor in its permanence.

STANDARDS YEARBOOK FOR 1930.

The Standards Yearbook for 1930, which was released last month, is more than a summary of interesting news. It covers broadly the developments in standardization during 1929 all over the world. In science, standards are the basis of countless kinds of measurement. New methods of measurement may begin in the laboratory. They graduate into industry. A measuring device at first a novelty of the laboratory may later control the process of a giant industry—the pyrometer for example, or the photo-electric cell.

Industry has become a vast complex of measurements controlling the design, making, and use of its products. Broadly, standardization is the measured control of industrial evolution. Hence it reaches out to touch every field of human activity. It includes simplification and "rationalization" as parts of a system designed to place the measurements of science in the controlling positions of industry.

The current Yearbook begins with an article on the Government's interest in advancing standardization and simplification, a discussion prepared by the former assistant director in charge of the commercial standardization group of the Bureau of Standards.

The Yearbook points out that to promote uniformity of national standards, wherever this is feasible and desirable, and to exchange information on standardization work in the different countries, an International Standards Association has been organized. This is supported by the national standardizing bodies of the following 18 countries: Austria, Belgium, Czechoslovakia, Denmarck, Finland, France, Germany, Holland, Hungary, Italy, Japan, Norway, Poland, Rumania, Russia, Sweden, Switzerland, and the United States. Thus, what is being done in the interests of national standardization in the United States by the American Standards Association, is about to be undertaken on a world-wide basis, and should result in great benefits to all the countries concerned. In this connection, it is interesting to note that 21 nations now have national standardizing bodies, though they do not all support the International Association at the present time.

The Yearbook records gratifying progress in the redetermination of the electrical units on a fundamental basis, thus

tying them in with the mechanical and thermal units, since all refer back to standards of length, mass and time. This work is being directed by the International Bureau on Weights and Measures, the research work itself being divided among the various national laboratories according to their facilities.

The publication of a revision of Rowland's preliminary table of solar spectrum wave-lengths is of fundamental importance in astronomy and physics. This paper was issued by the Carnegie Institution of Washington during the year and is based upon a recommendation of the International Astronomical Union. Part of the work was performed by the spectroscopy section of the Bureau of Standards.

An important event in connection with international standardization was the organization meeting, held in Mexico City, September 16 to 22 of the Pan American Institute of Geography and History. This institute is designed to further the interests of geography throughout the western hemisphere, this science being considered to include geodesy. Already there is an arc of continuous triangulation from northwestern Canada, across the United States, to the southern border of Mexico. It is hoped, in the near future, to extend this arc southward into Central and South America. Undoubtedly the Institute will have this in mind as one of the projects to advocate and push forward.

In his letter of transmittal to the Secretary of Commerce, Dr. George K. Burgess, Director of the Bureau of Standards, points out that, while, as in earlier issues of the Yearbook, special attention has been paid to the organization and procedure of the national standardizing agencies in the United States and abroad, the present volume likewise contains outlines of the activities and accomplishments of State, county, and municipal agencies, as well as those of technical societies and trade associations, "with special emphasis on their accomplishments during the year 1929, their program for future work, and the methods employed by each organization to encourage or facilitate the use of its standards and specifications."

Included among the special features of the 1930 Yearbook is an outline of important standardization activities in transportation, certain developments in the attempt to simplify the

calendar (contributed by C. F. Marvin, Chief of the United States Weather Bureau), and a bibliography of recent publications on standardization, furnished through the courtesy of W. A. Slade, chief of the division of bibliography of the Library of Congress.

Copies of this publication (Miscellaneous Publication No. 106 of the Bureau of Standards) may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 75 cents each.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, APRIL, 16, 1930.

The regular monthly meeting of the Institute was called to order by the President, Mr. Nathan Hayward, at eight-twenty-one P.M.

The President called upon the Secretary for a report of the business to be considered.

The Secretary stated that the minutes of the last regular meeting of the Institute had been published in full in the JOURNAL for April and moved that these minutes be approved as printed. The motion was seconded and was unanimously adopted. The President declared the minutes approved as printed.

The Secretary announced that there had been an addition of four Resident members to the rolls of the Institute since the last regular meeting and then proceeded to describe in considerable detail the progress which has been made in the organization for the prosecution of the campaign for funds for the Benjamin Franklin Memorial and Franklin Institute Museum to be built upon the Parkway. He announced that many of the outstanding leaders of Philadelphia life were manifesting a pleasing interest in the campaign and were coöperating in the organization of it. He stated that those in charge of the plans would feel themselves at liberty to call upon the members of the Institute and the friends of it, for any service which they might be thought able to render, and that this call for service would probably be made in the very early future. He bespoke as active support of the movement as the members could possibly give, in addition to whatever in the way of generous giving they might feel able to do.

The President then introduced as the speaker of the evening Dr. W. F. G. Swann, Director of the Bartol Research Foundation, who reported interestingly upon the work of the Bartol Laboratories during the last twelve months. Dr. Swann presented a very pleasing picture of the activities of the Laboratory and of the fruitful labors carried on there.

The paper of the evening was followed by a short discussion, after which the meeting adjourned with a vote of thanks to Dr. Swann, at nine-forty-three P.M.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, April 9, 1930.)

HALL OF THE COMMITTEE,
PHILADELPHIA, April 9, 1930.

MR. HENRY B. ALLEN *in the Chair.*

The following reports were presented for final action:

No. 2809: Method and Apparatus for Dry Cleaning Coal.

This report recommended the award of the John Price Wetherill Medal to Messrs. Henry M. Sutton, Walter L. Steele and Edwin G. Steele, of Dallas, Texas,

"In consideration of the development of old and unsuccessful methods of pneumatic separation of materials into a successful method for cleaning coal."

No. 2923: Clark Medal.

This report recommended the award of the Walton Clark Medal to Mr. Henry Latham Doherty, of New York,

"In consideration of his outstanding and valuable work in the development of the manufactured gas industry."

The following reports were presented for first reading:

No. 2908: Scattering and Diffraction of Electrons by Crystals.

No. 2911: Work of Doctor Kotaro Honda in Magnetism and Metallurgy.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, April 16, 1930.)

RESIDENT.

MR. PHILIP M. ALLEN, Advertising Agent, 14 West Chelten Avenue, Philadelphia, Pa.

MR. WILLIAM LINKER, Engineer and Building Contractor, 735 Cherry Street, Philadelphia, Pa.

MR. WILLIAM MESSINGER, Manufacturer, D Street, above Erie Avenue, Philadelphia, Pa.

MR. CHARLES W. RIVISE, Attorney Specializing in Patent Causes, 1321 Arch Street, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. C. R. CARY, Ellet Lane, Germantown, Philadelphia, Pa.

MR. FARNUM F. DORSEY, % Vacuum Oil Company, 61 Broadway, New York City.

MR. GEORGE W. EYRE, 135 Wayne Avenue, Springfield, Pa.

DR. EDWARD C. HAINES, George D. Wetherill Varnish Company, 113 Arch Street, Philadelphia, Pa.

MR. NATHANAEL G. HERRESHOFF, 6 Walley Street, Bristol, R. I.

MR. F. MACMURPHY, 306 South El Molino Avenue, Casa Del Njar Apartments, Pasadena, California.

MR. THADDEUS MERRIMAN, 346 Broadway, Board of Water Supply, New York City.

MR. JOHN F. METTEN, Union League of Philadelphia, Philadelphia, Pa.

MR. JOSEPH S. PECKER, 903 Victory Building, Philadelphia, Pa.

DR. RALPH PEMBERTON, Paoli, Pennsylvania.

DR. A. D. POWER, R. C. A. Radiotron Company, Inc., 415 South Fifth Street, Harrison, New Jersey.

MR. CARL D. PRATT, Reynolds Experimental Laboratory, Atlas Powder Company, Tamaqua, Pennsylvania.

PROFESSOR L. F. RONDINELLA, Head of Department of Art, Professor of Mechanical Drawing, West Philadelphia High School, Forty-eighth and Walnut Streets, Philadelphia, Pa.

HENRY P. RUST, ESQ., I. P. Morris and DeLaVergne, Inc., Richmond and Norris Streets, Philadelphia, Pa.

MR. J. WALDO SMITH, 346 Broadway, Room 1133, New York City.

MR. H. BIRCHARD TAYLOR, Cramp-Morris Industrials, Inc., Richmond and Norris Streets, Philadelphia, Pa.

MR. C. A. WOODBURY, Drawer B, Gibbstown, N. J.

NECROLOGY.

H. H. Furness, Jr., Philadelphia.
A. L. Webster, New York City.

LIBRARY NOTES.

RECENT ADDITIONS.

American Civil Engineers' Handbook. Fifth edition. 1930.

American Electrochemical Society. Transactions 1929, Volume 56. 1930.

American Society of Heating and Ventilating Engineers. Transaction 1927-1928, Volumes 33–34. Two volumes. 1929–1930.

ANDÉS, LOUIS EDGAR. Drying Oils, Boiled Oil, and Solid and Liquid Driers. 1917.

APPLEYARD, ROLLO. Pioneers of Electrical Communication. 1930.

ARMYTAGE, GEO. J. Metalwork for Schools and Colleges: its Principles and Practice. 1929.

AUERBACH, F. UND W. HORT. Handbuch der physikalischen und technischen Mechanik. Bd. 1, 3, 6. Three volumes. 1927–1929.

BOUCHER, JOHN NEWTON. William Kelly: a True History of the So-Called Bessemer Process. 1924.

BRITTEN, F. W. Horological Hints and Helps. 1930.

BROCA, ANDRÉ. Leçons d'Optique Physiologique Professées a l'Institut d'Optique Théorique et Appliquée. 1923.

BRUHAT, GEORGES. Traité de Polarimétrie. 1930.

CARTWRIGHT, H. MILLS. Photogravure: a Textbook on the Machine and Hand Processes. 1930.

Chemical Society. Annual Reports on the Progress of Chemistry for 1929, Volume 26. 1930.

Colloid Symposium Annual: Papers Presented at the Seventh Symposium on Colloid Chemistry, Johns Hopkins University, June, 1929. Edited by Harry Boyer Weiser. 1930.

DAY, ALLAN R. Inorganic Qualitative Chemical Analysis. 1930.

FABRY, CHARLES. Leçons de Photométrie Professées a l'Institut d'Optique Théorique et Appliquée. 1928.

HEATON, NOËL. Outlines of Paint Technology. 1928.

HELDT, P. M. Motor Vehicles and Tractors: a Textbook for Students and a Handbook for Engineers. 1929.

HERMANSEN, A. Industrial Furnace Technique. 1929.

HUDLESTON, L. J. Chemical Affinity. 1928.

LECOMTE, JEAN. Le Spectre Infrarouge. 1928.

LIPPMANN, EDMUND O. VON. Geschichte des Zuckers seit den ältesten Zeiten bis zum Beginn der Rübenzucker-Fabrikation. Ein Beitrag zur Kulturgeschichte. 1929.

LOBEL, L., AND M. DUBOIS. Manuel de Sensitométrie. 1929.

National Research Council. A Report of the Committee on the Construction and Equipment of Laboratories. 1930.

PAGÉ, VICTOR W. The Ford Model A Car: Construction, Operation, Repair. 1930.

PICKARD, J. A. Filtration and Filters: an Outline of the Art. 1929.

RAWLINGS, A. L. The Theory of the Gyroscopic Compass and its Deviations. 1929.

RICARDO, HARRY R. Engines of High Output: Thermodynamic Considerations 1929.

RICE, JAMES. Introduction to Statistical Mechanics for Students of Physics and Physical Chemistry. 1930.

ROBINSON, ALBERT E. The Application of Cellulose Lacquers and Enamels. 1929.

ROLLER, DUANE. The Termiology of Physical Science. 1929.

RUARK, ARTHUR EDWARD, AND HAROLD CLAYTON UREY. Atoms, Molecules and Quanta. First edition. 1930.

SCHUHLER, ALBERT A. Electric Wiring: a Textbook of Applied Electricity for Vocational and Trade Schools. Second edition. 1930.

SHIRLEY, ALFRED J. Elementary Craftwork in Metal: an Introduction for the Use of Teachers, Students, and Workers. 1928.

SHOOP, CHARLES F., AND GEORGE L. TUVE. Mechanical Engineering Laboratory Practice. 1930.

SIEGBAHN, MANNE. The Spectroscopy of X-rays. Translated with the author's additions by George A. Lindsay. 1925.

STAMBERGER, PAUL. The Colloid Chemistry of Rubber. 1929.

STARLING, SYDNEY G. Electricity and Magnetism for Advanced Students. 1929.

STEPHENSON, MARJORIE. Bacterial Metabolism. 1930.

Wasserkraft-Jahrbuch 1928–29. Vierter Jahrgang. 1929.

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YVON, GUSTAVE. Controle des Surfaces Optiques: Qualité des Systèmes Optiques. 1926.

Zeitschrift für Untersuchung der Nahrungs-und Genussmittel sowie der Gebrauchsgegenstände. Generalregister Bd. 17–50 und Beilage-Band 1–17, Jahrgänge 1909–1925. 1929.

ZELENY, ANTHONY. Elements of Electricity. First edition. 1930.

BOOK REVIEWS.

THE KINEMATICAL DESIGN OF COUPLINGS IN INSTRUMENT MECHANISMS. By A. F. C. Pollard, A.R.C.S., A.M.I.E.E., Professor of Instrument Design at the Imperial College of Science and Technology. 64 pages, 12mo., cloth. London, Adam Hilger, Ltd., 1929. Price, 4s. 6d.

The proportioning of the component parts of a mechanism is generally regarded first and foremost a geometric process to which analytic methods may be applied and the desired dimensions determined. The selection of these elements to effect the required motion is in the vast majority of cases a matter of invention, judgment and precedent. Writers on the principles of kinematics have at times made painstaking efforts to discover a classification which might be employed in a system of analytical procedure for a determination of the most suitable elements. Perhaps the most notable attempt in that direction was that of the celebrated Professor Reuleaux in his Kinematics, but no analytical system of procedure appears even to have supplanted the simple exercise of the inventive faculty, beyond the classification brought to such a tentative process as the consideration of the accepted forms of kinematic elements, turning and sliding pairs, higher and lower pairs and the like.

Professor Pollard directs attention to the unsuitability of the design of couplings employed in machine-tool parts to instrument mechanisms. The machine-tool industry is an old one, while that of instrument design is relatively recent, and doubtless many instrument designers who were recruited from the former industry with its time-honored precedents are responsible for this adoption of designs imposed by the large stresses to which machine-tool parts are subjected to instrument parts under inappreciable stress. With view to providing a well-defined set of principles for the guidance of the instrument designer the author describes the behavior of the action of the moving elements of instruments in general and the classification of couplings used for them, and discusses the features of kinematic design of several modern optical instruments. Couplings are classified according to their degrees of freedom and though that kind of classification may be of value in specification it is doubtful whether instrument design will not be as fully governed by precedent and process of evolution as has been the machine-tool designer, who also in recent times has applied many refinements of a rational nature to his art.

The book is of undoubted value in pointing out the salient features of good practice in the design of the mechanism of control in instruments of physical science.

LUCIEN E. PICOLET.

ATOMS, MOLECULES AND QUANTA. By Arthur Edward Ruark, Ph.D., Physicist, Mellon Institute of Industrial Research, Lecturer in Physics at the University of Pittsburgh and Harold Clayton Urey, Ph.D., Associate Professor of Chemistry at Columbia University. First Edition, xvii–790 pages, McGraw-Hill Book Company, Inc., New York, 1930. Price, $7.00.

The authors have written this book with a twofold purpose in mind. Their intention has been, first, to provide the uninitiated with a comprehensive introduction to the study of atomic and molecular structure and, second, to furnish a

thoroughly modern exposition on the laws of quantum theory and a general account of the more important researches in this field. Although the trend of modern physical theory is toward the establishment of purely mathematical relationships between observable facts, Ruark and Urey have displayed no radical tendencies and have not sought to separate theory from the mechanical concepts in which it had its inception. However, they have been careful to point out the shortcomings inherent in most of these mechanical interpretations and thus prepare the way for the introduction of the more abstruse studies of wave mechanics and matrices.

The subject matter has been arranged in a logical sequence. Following the introduction, there is a chapter on the elementary constituents of the atom. The foundations of the quantum theory are outlined briefly and a review of dynamical principles inserted preparatory to a lengthy discussion on atomic and molecular spectra. Particular attention has been paid to the spectra of hydrogenic atoms for it is upon the study of these simpler types that are based many of the fundamental concepts of modern physics. The interpretation of molecular constitution from infra-red spectra is outlined briefly. A chapter on Critical Potentials of Atoms and Molecules discusses the phenomena of photoelectric and inverse photoelectric effects in gases, chemical activation by electron impact, and the Ramsauer effect. Due to collisions of the second kind there are the phenomena of sensitized fluorescence, the quenching of resonance radiation and photosensitized reactions. The latter portion of the book is devoted to a comprehensive exposition of wave and matrix mechanics and the close interrelation between these two independently evolved theories. This is followed with chapters on the interpretation of the characteristics of atoms and molecules in the light of the new mechanics. The last chapter covers the subject of the refraction of electrons and atoms by crystals. A series of nine appendices covering various mathematical formulations and interpretations should prove particularly valuable to the student and scholar.

T. K. CLEVELAND.

LA STRUCTURE DE LA LUMIÈRE. Par Sir J. J. Thomson, O.M., F.R.S., Master of Trinity College, Traduit par R. Fric, ingénieur (E. S. E.) Avec une préface par M. A. Cotton, Membre de l'Institut. xi–50 pages, 8vo, paper. Paris, Librairie Scientifique, Albert Blanchard, 1929. Price, 9 francs.

French readers are fortunate in the initiative of the house of Blanchard in issuing a collection of foreign scientific monographs which places in their hands a collection of important works by celebrated English, German, Italian and Russian authors. The series is published under the direction of Professor G. Juvet of the University of Neuchatel. The present volume is the second in the series from the works of Professor Thomson, the first being "The Electron in Chemistry," the report of a series of four lectures which were delivered by the *grand maitre* before this Institute in 1923. This second contribution consists of the Fison Memorial Lecture, 1925, and papers on the structure of light.

It is the consideration of the structure of light, the operative mechanism of radiation, which has so disturbed the harmony of the previously reasonably happy family of physical science and Professor Thomson's large share towards adjusting these differences have been prompt to reach all important centers. These lectures

are therefore not new to English speaking readers, but Professor Thomson, who enjoys the happy faculty of reaching dizzy heights in mathematical physics and also of bringing his subject within the realm of engineering mathematcis, will be no less welcome among those who follow him in French on a second reading, a most unusual opportunity at once to review a profitable study and to test their capacity to master the French discourse on a subject which is far from the easiest that might be chosen for that purpose.

L. E. P.

WASSERKRAFT—JAHRBUCH, 1928–29 (4 Jahrgang). Herausgeber: Geheimer Baurat, Oberdirektor Dr. Ing. e. h. K. Dantscher, Ord. Professor d. Technischen Hochschule München; Ingenieur Carl Reindl, München. 487 pages, illustrations, 8vo, München, G. Hirth Verlag, A. G., 1929. Price, 22 marks.

The fourth issue of this publication contains the most recent data on the development of water power plants in Continental Europe. A paper reviewing the results of water power development in Austria during the past ten years with some indications of its future possibilities is the leading article and there are also reports on the progress of the utilization of water power in Italy, France, Norway, Finland, Iceland, Czechoslovakia and Greece. The legal aspects of the water power problem are discussed in the second part of the volume which also contains special contributions on the subject from engineers representing the several countries.

The problem of the constructon of power houses and other structures and their architectural requirements is given attention in the third part of the volume. The closing portion is devoted to water power machinery and we are glad to note, that a Philadephia engineer leads off with an article on the progress of hydraulic turbines in the United States to the year 1929. The paper, presswork and printing are up to the usual standard.

R.

THE CONSTRUCTION AND EQUIPMENT OF CHEMICAL LABORATORIES. A report of the National Research Council Committee. 340 pages, illustrations, 8vo. The Chemical Foundation, Inc., New York, 1930. Price, $1.00.

In the mid-Victorian era, so much deprecated nowadays, the standard dictionaries tell us that the word "laboratory" meant "a chemist's work-shop," hence in those days the title, chemical laboratory, would have been tautology. Times are changed and we are changed with them, as the Roman proverb has it. Now the scientific work-shops cover so many phases of investigation and instruction that the nature of the laboratory has to be defined. In view of the stress of modern science, "laboratory" might be defined in general terms, as "a place of hard work and frequent disappointment."

Half a century ago, books of laboratory manipulation were quite familiar. A volume of considerable size was available, giving methods of heating, filtering, distilling and all of the other numerous manipulations in chemical work. Such laboratories as the Bacteriologic, Histologic and the Psychologic were unknown, but the world has become now intensely "ological" as Mrs. Gradgrind says. For some reason the popularity of these special works on manipulations declined very materially and they have not been familiar for a long while. Chemical laboratories in those days were largely either private affairs of persons engaged in general chemical practice or they were connected with colleges, partly for instruction,

partly for research. In recent years an enormous development of laboratories in connection with industries or utilities corporations has rendered necessary a scientific study of the character of the buildings and equipments therein. In the days gone by the laboratory was often merely a small room, perhaps in the basement, perhaps in the top floor, inconvenient both as to access and use. Today, the civilized nations are so actively engaged in all varieties of research that laboratories of imposing structure and elaborate equipment are prominent everywhere.

The book in hand is an ambitious and interesting effort to set forth the results of the experience of those who have constructed and operated modern laboratories. A very large amount of useful and trustworthy information is given in its pages. The data are in large part made up of replies to a questionnaire to over a hundred colleges and universities, which met with a liberal response. In addition, all the members of the Committee that had charge of the preparation of the volume have had experience in construction, equipping and operating high-class laboratories. The book will undoubtedly, therefore, be a valuable guide to those who are about to establish a chemical laboratory for instruction or research. Excellent illustrations of various constructions are given together with many views of actual installation.

HENRY LEFFMANN.

TRAITÉ DE POLARIMÉTRIE. Par Georges Bruhat, Professeur a la Faculté des Sciences de Paris, avec préface de A. Cotton, Membre de l'Institut. xvi–447 pages, 8vo, cloth. Paris, Revue d'Optique théorique et instrumentale, 1930. Price 65 francs.

Of deep interest alike to the physicist in fundamental questions of light-propagation, and to the technologist as a valuable method of optical analysis, polarimetry holds a most important place in physical science. But for the phenomena of polarization, the disturbance in the ether which constitutes the propogation of light might take place equally in the direction of the ray or transverse to it: polarization determines the transverse character of the disturbance. The present treatise embraces the discovery, theory and development of polarization with a consideration of its applications and matters of technique which relate to that important art.

The book is in two major divisions; the first on polarimetric apparatus, the second on the phenomena of rotary polarization and their applications. The evolution of polariscopes which follows a general review of fundamentals is carried as far as a consideration of the more refined apparatus which effect the measurement of rotary dispersion in the visible spectrum and into the infra-red and ultra-violet. The author is a bit apologetic for dwelling rather extensively on the historic features and theoretic analysis of apparatus, as on polarizing prisms, the different methods of determining the amount of rotation, the geometric optics of polarimeters, and apparatus for the production of monochromatic light of variable wave-length. Most readers will find that a virtue rather than a fault. Professor Cotton who writes the illuminating preface says regarding the practice of polarimetry: "The technique of polarimetric measurement has made great progress. Not only have apparatus been perfected, but adequately pure monochromatic light of great brilliancy has become available; and the quality of the light-source has an important influence on the results. It is interesting to compare

modern apparatus with that which Biot used more than forty years ago in which the polarizer was simply a mirror of black glass. Biot was so expert in the use of this apparatus, however imperfect, that he persistently preferred it to nicol prisms toward which, even as late as 1860, he was unsparing of criticism. He certainly would have changed his views had he experimented with the normal-field polarizers, such as Lippich was the first to construct and resulted in a closer study of polarization in spar prisms. He would have been deeply impressed, in viewing the sun through two of these crossed prisms, to observe the complete extinction of the light when with the black mirrors or nicols, there remains an intolerable residual light."

In the second part stress is laid on general laws in the presentation at length of such representative topics as; the rotary polarization of monochromatic light, molecular dissymmetry and racemism, a consideration of the methods of stereochemistry, rotary dispersion and its physico-chemical significance. In these chapters, have been collated and generalized a vast array of experimental and theoretical data. The author states, in that connection, that a complete collection of citations is precluded by the extent of available material but, he believes, none that has important bearing on general laws has been omitted. The reference to citations directs attention to the copious bibliography. There are 882 numbered citations at the end of the volume to which reference is constantly made throughout the text. An index under name and another under subject is provided both for these citations and for the subject-matter of the volume. References to the book are in normal type, those to citations in heavy type. The book is unusually well arranged for efficient reference. Final chapters deal with the procedure in polarimetric determination of solution concentrations, mainly in saccharimetry, crystalline rotary polarization, and an examination and discussion of the phenomena of magnetic polarization and the apparatus employed in its study.

The work is an unusually complete account of the principles and modern practice of polarimetry arranged in a most convenient form for efficient study and reference.

L. E. P.

L'ANCIENNE ET LA NOUVELLE THEORIE DES QUANTA. Par Eugene Bloch, Professeur de Physique theorique et Physique celeste a la Sorbonne, v–417 pages, 8vo, paper, Paris, Librairie Scientifique Hermann et Cie. Price, 90 francs.

Casually considered, there is a striking analogy between the indivisible parcels of matter in the atomic theory of Dalton and the similarly indivisible parcels of energy which are premised in the quantum hypothesis of Planck. Like its forerunner in the field of chemistry, the quantum theory has gradually assumed a dominant position in the structure of physical science. A study of quantum accordingly entails passing into review the entire structure of physics. These new views are still in a formative state which, despite immediate applicability, are not yet ripe for translation into a didactic treatise. Professor Bloch has adopted the obvious alternative of giving an abridged account, but a comprehensive one, of the development of the quantum theory and the atomistic phenomena which relate to it. The subject-matter of this volume consists essentially of the substance of courses given at the Sorbonne during the scholastic years of 1926–1927 and 1928–

1929 on the theory of quanta. The course of the intermediate year 1927–1928 was on magnetism and magneto-optics. This also included matters relating to the theory of quanta, and some of the material of that course is also utilized. Certain intermediary material essential to the transition from classroom form to text is added to insure a homogeneous presentation.

The character of the course from which the work has been derived is maintained, says the author; that is, a somewhat arbitrary choice of topics has been made and a large number of important but not vital ones to the present purpose are intentionally omitted. The historic features are especially dwelt upon in illustrating progressive development by the selection of material of the most representative type. The work is in twenty chapters. The first ten chapters are devoted to an examination of the theory of quanta in its original form due to Bohr and Sommerfeld. The principal questions discussed are: the Planck formula, the photoelectric effect, the Doppler-Fizeau effect, the Compton effect, the periodic classification of the elements, atomic magnetism, and a number of spectroscopic problems: hydrogen atom, spectral ray series, Zeeman effect.

Chapters eleven and twelve, the author further points out, may be considered as a transition between the two halves of the work. Thereby he has reconciled the essentials of analytic mechanics and the general results of the old theory of quanta (principle of correspondence, adiabatic invariants). Finally, chapters thirteen to twenty treat of the modern quantic theories. Beginning with a consideration of the waves of Louis de Broglie, the author develops the concepts of Schrodinger and the results of the celebrated equation established by this physicist. The mechanics of matrices then receive attention and its equivalence to undulatory mechanics is shown.

The work, which is an introduction designed primarily for readers who are making their first acquaintance with the subject, is kept at a reasonably elementary level. A very substantial mathematical training is however essential to the satisfactory perusal of this deductive account of a most important principle in modern physics.

L. E. P.

BEARING METALS AND BEARINGS. By W. M. Corse, Consulting Metallurgical Engineer, Secretary Institute of Metals Division, American Institute of Mining and Metallurgical Engineers. 383 pages, 8vo, cloth. New York, Chemical Catalog Company, Inc., 1930. Price, $7.00.

Of all the component parts that enter into the construction of a machine, there is none upon which satisfactory performance is more dependent than the bearings which support the moving parts. As is well known to habitual readers of engineering periodicals the recorded results of a large amount of study and experiment are hidden away in journalistic material covering a span of many years. This is accessible in the yearly volumes of the few indexes to technical literature whose publication has been maintained up to the present time. The labor of making a search of a subject of this kind entails considerable labor, especially as the classification of topics is necessarily very general in an index which covers a miscellaneous collection of technical data. In point of economy of effort, the advantage is obvious of a bibliography of the subject, classified according to its accepted term-

inology, within the convenient dimensions of this octavo volume of moderate thickness. In addition to the bibliography of nearly thirteen hundred entries, there is a well assorted collection of 233 abstracts of representative papers. Many of these are given at ample length, and in many cases will satisfy most purposes of reference. A historical summary and general survey of the state of the art occupy thirty-eight pages at the beginning of the book. In this, will be found references to the most modern practice in the composition and treatment of bearing-metal alloys and the most recent methods of testing their properties. Sixteen tables exhibiting the properties of alloys and indexes of names and subjects complete the volume.

The work should prove of great value to any one who is investigating bearing metals or seeking guidance in specifying their composition and method of manufacture.

LUCIEN E. PICOLET.

THE USE OF THE MICROSCOPE. By John Belling, Carnegie Institution of Washington. 315 pages, illustrations, 8vo. New York, McGraw-Hill Book Company, 1930. Price, $4.00.

The author announces himself on the title-page as a "cytologist." The book evidences this specialism, but there is a large amount of information concerning the construction of standard microscopes, the optical principles involved and the details necessary for securing satisfactory results. Much valuable advice is given as to care of the instrument.

The microscope and the telescope are fundamentally of the same type, both being employed for magnification. Many persons unfamiliar with optical principles regard the telescope as merely "bringing things nearer," but the scientist knows that this is not the case. Recent advances have added greatly to the power of the telescope and we now hear of galaxies so far from this earth that the distance can only be expressed in "light-years." No doubt the observation of some of the celestial sights, such as the Moon, Saturn, or the great nebula in Orion impresses the observer with a sense of his own littleness and the littleness of the planet on which he lives. "By night," said Young, "an atheist half believes a god." After all, however, the microscope has been of greater service to mankind than the telescope. The object of science is the discovery of truth, whether useful or not, and the duty of the scientist to proclaim the truth when found. No one should deprecate the recondite researches of the star-gazer, but in this troubled world we must feel that of the two magnifying instruments, the microscope has contributed much more to the relief of human ills and the extension of human comfort. Vast advances have been made in detecting the germs of disease and in unravelling the nature of physiologic phenomena in living organisms, with promise of greater discoveries in the future due to the labors of microscopists.

Progress in the application of the microscope to the solution of biologic problems has been due to many patient and self-sacrificing investigators, among which must not be forgotten those who have devoted themselves to perfecting the optical and mechanical details of the instrument. Considering the many difficulties that have to be met, it may be said with confidence that the modern microscope is the most perfect instrument employed in research. At present the popular instruments of the research laboratory, whether in biology, metallurgy or petrol-

ogy, are complicated and expensive and viewing some of the most recent forms, grace seems to have been completely sacrificed to mechanical and optical efficiency, but this cannot be helped.

Mr. Belling has written an informing and commendable work. His point of view is entirely that of the more or less transparent field and we have, therefore, no information on the examination of opaque objects. These are left to the mineralogist and metallurgist. There is also no presentation of the application of polarized light, nor are the methods of using ultra-violet light and ultra-miscroscopic instruments described. Within the field to which the book is devoted, the information is excellent and comprehensive. Strictly speaking, the words "in Biology" should be added to the title of the book.

The reviewer has noted with some astonishment that none of the recent works on the microscope mentions the "super-microscope" advertised by a London firm which gave in its literature striking examples of the value of the instrument in photomicrography.

HENRY LEFFMANN.

ADVANCED MATHEMATICS FOR STUDENTS OF PHYSICS AND ENGINEERING. By D. Humphrey, B.A., B.Sc., Head of the Department of Mathematics and Physics, The Polytechnic, London. Part I, viii–120 pages, Part II, viii–175 pages, in one volume, 8vo, cloth. New York, Oxford University Press, 1929. Price, $4.25.

Authors have not been negligent in supplying texts designed to meet the ever advancing mathematical requirements of students in physical science and engineering, and a considerable number of meritorious books with that object in view have appeared. Some are intended for students in engineering, others for students in physics and chemistry; again, others are of a comprehensive character. In variety of topics covered, the present volume may be properly included in the latter class with the qualification of judicious condensation and what the author considers expedient omission. The choice of topics has been more or less arbitrary and governed by the particular needs of the courses at the Polytechnic.

The work deals mainly with the operations and applications of the differential calculus which are developed in formal texts. Some of the theorems of that subject are here treated with greater brevity than in these texts while others are amplified. In addition to those topics, a number of theorems which are commonly found in works on advanced algebra and trigonometry have been included. Among these are an examination of convergency, a *regula falsi* for the approximate roots of equations and complex quantities. In the discussion of the latter, De Moivre's theorem is proved for a positive integral exponent: proofs of the theorem for fractional and negative exponents are omitted as "long and difficult." However, trigonometries which contain this theorem are numerous, and an inquisitive student will be agreeably disappointed at the brevity and relative simplicity of the proof in Todhunter's Trigonometry. Simon-pure mathematicians look somewhat askance on the free use of geometric illustration but an exception might be made in geometrically illustrating the meaning of the delta-differential coefficients and the d-differentials in the total differential of a function of two variables. A student can reproduce the formula from the diagram if perchance he has forgotten it, but it is doubtful whether he can as safely write out the ana-

lytical argument. This examination of partial differentiation, and the maxima and minima of implicit functions, and of functions of two or more variables is made at considerable length.

Differential equations, which are of paramount importance in physical science, properly receive an unusually full treatment, The subject is segregated between Part I and Part II, the more difficult phases being treated in Part II. In these as indeed in other topics explanatory examples are employed to clarify the demonstration of a theorem rather than lengthy explanations. Explanatory matter, however, if condensed, is adequate in a work of this kind which covers an extensive territory in a volume of moderate dimensions. Linear differential equations of the first and second order, linear equations with constant coefficients of higher orders, partial differential equations, three variable differential equations and a number of allied theorems are discussed according to the methods employed in advanced text-books. Solid analytical geometry, the solution of numerical equations, and determinants are topics which one would expect to seek elsewhere, but since they are of frequent application, it is fortunate that space has been found for them. More in keeping with the general character of the book are the calculus of finite differences, method of least squares and Fourier series. The directly applicable portions of these subjects which the author analyzes and plentifully illustrates should prove most valuable to students in physics and engineering. The modern student will especially welcome the last chapter which is on vector analysis. Authors of physical science subjects now use the vector method with the greatest freedom, and in order to read their works with satisfaction, a working knowledge of that method has become essential.

The work is a rarely well-chosen collection of topics of vital value to students in physical science and engineering.

LUCIEN E. PICOLET.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 334. The Torsion of Members Having Sections Common in Aircraft Construction. By George W. Trayer and H. W. March. 48 pages, illustrations, quarto. Washington, Government Printing Office, price, 25 cents.

This publication presents the results of investigations of the torsion of structural members undertaken by the Forest Products Laboratory.

Within recent years a great variety of approximate torsion formulas and drafting-room processes have been advocated. In some of these, especially where mathematical considerations are involved, the results are extremely complex and are not generally intelligible to engineers. The principal object of the investigation was to determine by experiment and theoretical investigation how accurate the more common of these formulas are and on what assumptions they are founded, and, if none of the proposed methods proved to be reasonably accurate in practice, to produce simple, practical formulas from reasonably correct assumptions, backed by experiment. A second object was to collect in readily accessible form the most useful of known results for the more common sections.

This report reviews informally the fundamental theory of torsion and shows how the more common formulas are developed from it. Formulas for all the important solid sections that have yielded to mathematical treatment are listed.

Then follows a discussion of the torsion of tubular rods with formulas both rigorous and approximate.

It is shown by a series of tests of prisms of simple section that wood is a suitable material for the experimental investigation of the torsion problem. Accordingly, wood was used for the experiments on full-sized members because of the ease with which it can be worked into different shapes and because of its low torsional stiffness. The possible effect of different moduli of rigidity in radial and tangential planes was investigated mathematically, and the effects of rate of loading and of moisture content were determined experimentally. Furthermore, soap films were used in order to take advantage of a mathematical similarity that exists between the torsion problem and the problem of finding the deflection of a thin membrane under pressure. The analogy is discussed in detail in the report.

Our experimental work with beams of irregular sections that have not yielded to mathematical treatment is described. From these experiments and certain mathematical considerations, empirical formulas are set up for irregular sections whose component parts are rectangles.

Report No. 338. The Effect of Reduction Gearing on Propeller-Body Interference as Shown by Full-Scale Wind-Tunnel Tests. By Fred E. Weick. 21 pages, illustrations, quarto. Washington, Government Printing Office, 1930, price 15 cents.

Full-scale tests have been made in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics, on a 10-foot 5-inch propeller on a geared J-5 engine and also on a similar 8-foot 11-inch propeller on a direct-drive J-5 engine. Each propeller was tested at two different pitch settings, and with a large and a small fuselage. The investigation was made in such a manner that the propeller-body interference factors were isolated, and it was found that, considering this interference only, the geared propellers had an appreciable advantage in propulsive efficiency, partially due to the larger diameter of the propellers with respect to the bodies, and partially because the geared propellers were located farther ahead of the engines and bodies.

Report No. 341. The Design and Development of an Automatic Injection Valve with an Annular Orifice of Varying Area. By William F. Joachim, Chester W. Hicks, and Hampton H. Foster. 10 pages, illustrations, quarto. Washington, Government Printing Office, 1930, price, 10 cents.

The injection valve described in this report was designed and developed at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics in connection with a general research on aircraft oil engines. The purpose of this investigation was to provide an automatic injection valve of simple construction which would produce a finely atomized oil spray of broad cone angle and would fulfill the requirements of fuel injection in aircraft oil engines. The injection valve designed has only six parts—i.e., two concentric nozzle tubes flared at one end, two body parts, and two nuts. The nozzle tubes are provided with seats at the flared ends to form an annular orifice which automatically varies in area with the injection pressure. Adjustment of the nuts determines the valve-opening pressure. The fuel passage to the orifice is provided by the clearance space between the nozzle tubes. When sufficient oil pressure is developed by the

fuel pump, the flared ends of the nozzle tubes move apart slightly, and the oil passes through the annular orifice, producing a broad conical spray. The nozzle tubes are so constructed as to cause the cylinder gases to heat them approximately 500° F., which preheats the oil and tends to reduce the ignition lag.

The results of tests made with the N. A. C. A. Spray Photography Equipment on this injection valve indicate the effect of several factors on spray penetration. For a duration of injection of 0.003 second, and a valve-opening pressure of 2,500 lb. per sq. in., a change of injection pressure from 6,000 to 10,000 lb. per sq. in. increased the penetration 25 per cent. For a constant speed and fuel quantity per cycle a change of valve-opening pressure from 2,000 to 5,000 lb. per sq. in., which caused a corresponding change in maximum injection pressure from 6,700 to 10,500 lb. per sq. in., increased the penetration 5 per cent. A change of spray-chamber air density corresponding to a change of compression ratio of from 11.2 to 15.3 decreased the spray penetration 8 per cent. Curves are presented showing these effects together with the effect of engine-operating temperature on the valve-opening pressure.

Analysis and engine tests indicate that the fuel spray from this type of injection valve has characteristics which reduce the time lag of autoignition and promote efficient combustion in high-speed oil engines.

Bibliography of Aeronautics, 1928. 214 pages, quarto, Washington, Government Printing Office, 1930, price, 50 cents.

This volume covers the aeronautical literature published from January 1 to December 31, 1928. The first Bibliography of Aeronautics was published by the Smithsonian Institution as Volume 55 of the Smithsonian Miscellaneaous Collections and covered the material published prior to June 30, 1909. Supplementary volumes of the Bibliography of Aeronautics for the subsequent years have been published by the National Advisory Committee for Aeronautics. They are for the years 1909–1916, 1917–1919, 1920–1921, 1922, 1923, 1924, 1925, 1926, and 1927.

As in previous volumes, citations of the publications of all nations are included in the languages in which these publications originally appeared. The arrangement is in dictionary form with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of the cost of presentation but an attempt has been made to give sufficient cross reference for research in special lines.

ERRATUM.

THE TERMINOLOGY OF PHYSICAL SCIENCE. By Duane Roller. 115 pages, 12mo, paper. Norman, Oklahoma, University of Oklahoma Press, 1929. Price $1.00, page 565, April 1930.

First paragraph, should read:

In the specification of a quantity of any kind in physical science, it is of supreme importance that it shall invariably convey a meaning with unmistakable precision. The study of physical science has not always been the vast cooperative effort of world-wide extent that, in effect, it has become in modern times, and what

confusion still persists in its terminology, incident to the isolated efforts to which it owes its early rise and even its later progress, is obviously enough inevitable. Modern investigators have done much to eliminate these uncertainties, but old habits of expression, which have survived by the weight of authority, only gradually make way for a more carefully considered definition of terms. Careful habit of expression as well as of thought at an early period of study is an invaluable asset for future progress, and in preparing this critical review, the author has had in mind the needs of the teacher and the text-book writer and not those of the student for, as he points out, dialectic discussions have no place in the class-room.

PUBLICATIONS RECEIVED.

A Report of the National Research Council Committee on the Construction and Equipment of Chemical Laboratories, with index of dealers in laboratory equipment and apparatus. 340 pages, illustrations, 8vo. New York, The Chemical Foundation, Inc., 1930. Price $1.00.

Advanced Mathematics for Students of Physics and Engineering, by D. Humphrey, B.A., B.Sc. Parts one and two. 120 + 175 pages, illustrations, 8vo. Oxford University Press, 1929. Price $4.25.

The Use of the Microscope. A handbook for routine and research work, by John Belling. 315 pages, illustrations, 8vo. New York, McGraw-Hill Book Company, Inc. 1930. Price $4.00.

Worked Examples in Electrical Technology, by F. Peasgood and H. J. Boyland. 219 pages, illustrations, 8vo. Oxford University Press, 1929. Price $5.00.

Magnetism, by Edmund C. Stoner Ph.D., with a general preface by O. W. Richardson, F.R.S. 117 pages, illustrations, 16mo. New York, E. P. Dutton and Company, Inc. Price $1.10.

The Conduction of Electricity through Gases, by K. G. Emeléus, Ph.D., with a general preface by O. W. Richardson, F.R.S. 94 pages, illustrations, 16mo. New York, E. P. Dutton and Company, Inc. Price $1.10.

Bibliography of Aeronautics, 1928. National Advisory Committee for Aeronautics. 214 pages, quarto. Washington, Government Printing Office, 1930. Price 50 cents.

Introduction a l'Étude de la Mécanique Ondulatoire par Louis de Broglie. 292 pages, illustrations, portrait, 8vo. Paris, Librairie Scientifique Hermann et Cie, 1930. Price 85 francs.

Recueil d'Exposés sur les Ondes et Corpuscules, par Louis de Broglie. 81 pages, 8vo. Paris, Librairie Scientifique, Hermann et Cie., 1930, price 20 francs.

Conservatoire National des Arts et Metiers. Conferences d'Actualities Scientifique et Industrielles. Annee 1929. M.M. L. de Broglie, G. Foex, E. Bloch, L. Dunoyer, G. Ribaud, Lt. Col. Jullien, L. Bloch, V. Kammerer, Rene Mesny. 271 pages, illustrations, 8vo. Paris Librairie Scientifique Hermann et Cié., 1930. Price 35 francs.

Abstract-Bulletin of Lamp Development Laboratory, Incadescent Lamp Department of General Electric Company, Nela Park, Cleveland, Ohio, Vol. II, No. 1, January 1930. 163 pages, illustrations, plates, 8vo. Cleveland, Lamp Development Laboratory, 1930.

U. S. Department of Agriculture, Weather Bureau. Daily river stages at river gage stations on the principal rivers of the United States, Vol. XXVI, for the year 1928, by H. C. Frankenfield, principal meteorologist. 290 pages, quarto. Washington, Government Printing Office, 1930. Price 60 cents.

Royal Society of Arts, Cantor Lectures on Wind Instruments from Musical and Scientific Aspects, by E. G. Richardson, Ph.D., D.Sc., delivered before the Royal Society of Arts, November and December 1929. 38 pages, illustrations, 8vo. London, Society, 1930. Price 2 shillings 6 pence.

National Advisory Committee for Aeronautics. Technical Notes: No. 334, Comparative performance obtained with XF7C-1 airplane using several different engine cowlings, by Oscar W. Schey, Ernest Johnson and Melvin N. Gough. 17 pages, illustrations, quarto. No. 335, The structure and properties of parachute cloths, by H. J. McNicholas and A. F. Hedrick. 28 pages, illustrations, quarto. No. 336, The effect of wing tip floating ailerons on the autorotation of a monoplane wing model by Montgomery Knight and Carl J. Wenziger. 19 pages, illustrations, quarto. Washington, Committee, 1930.

Third (Triennial) Empire Mining and Metallurgical Congress, South Africa, 1930. Papers presented at the Congress. 64 pamphlets, illustrations, plates, maps, 8vo.

CURRENT TOPICS.

Ultramicroscopic Analysis of Vibrations of the Air. Z. CARRIÈRE. (*Jour. de Phys. et le Radium*, May, 1929.) Very small dust particles are disseminated in the air contained in a tube and their motion is observed by an ultramicroscope while the air is maintained in vibration. The tube or pipe in which the motions of the particles were followed was 35 mm. in diameter and 170 cm. long. Both ends were closed and there were no apertures in the walls except one of very small size leading to an air pump and a second for the introduction of dust. One end of the tube was closed by the diaphragm of a telephone. This, joined to an alternating commercial circuit of 50 cycles per sec., served to keep the enclosed air in vibration. The light from a Nernst filament or an arc lamp entered the tube through a window and was brought to a focus where observations were to be made. By drawing air through the tube while a bellows blew dust into it the distribution of the dust was controlled. A microscope of long focal length was focussed on the particles. For the frequency of the lighting circuit and at temperature 20° C. of the air the length of the air column was chosen so that there should be nodes at both ends and an antinode at the middle, where the motions of the particles were to be scrutinized through a window in the tube.

With the telephone diaphragm at rest the microscope showed a group of bright points with an approximately uniform drift in one direction. The observer could single out a point and follow its course. Upon exciting the telephone each point under observation changed into a bright line parallel to the axis of the tube. There still remains a drifting motion of the assemblage of particles, but the two motions of drift need not be in the same direction. With a steady state of vibration of the air in the tube the length of the bright lines measures twice the amplitude of an air particle at the point of observation, provided that the dust particle giving the line is small enough and light enough. An examination of the conditions of the experiment led to the conclusion that the amplitude of vibration of an air particle exceeded that of an adjacent dust particle by one two-thousandth only. By the use of a measuring arrangement in the ocular of the microscope the lengths of the bright lines were obtained.

The amplitudes of air particles at the middle of the tube were obtained for different voltages applied to the telephone whose

resistance was 200 ohms. For 22 volts the amplitude was .15 mm. and for 72 volts 1.80 mm. Thus the amplitude increased much more rapidly than the impressed voltage. In another experiment the amplitude of the telephone diaphragm was measured by an auxiliary microscope. In all cases the amplitude of the air at the antinode was much greater than that of the center of the diaphragm. The ratio of the two amplitudes ranged from 4.1 for a small voltage to 8.6 for the highest permissible voltage.

Since this method of examining the amplitudes of vibration within the tube has the merit of introducing but little disturbance into the conditions previously existing it is very suitable for a study of changes in amplitude across the tube as the walls are approached. Such a study shows that the amplitude is constant for about 30 mm. of the width of the tube. About 1 mm. from each side of the tube there is a maximum of amplitude exceeding by about 10 per cent. that of the central part. From the maximum position the amplitude decreases to zero in the distance of a mm. as the walls are reached.

The method permits also of the examination of the oscillations of air in the tube when a small solid cylinder is introduced into the air column with its axis perpendicular to the length of the column. In that case there are places where ellipses are described by the particles and the direction of vibration at different positions with respect to the disturbing cylinder can be readily traced. The author suggests that his method be used for the calibration of phonometers. It may further be used as a standard source of sound by the removal of one end of the tube and an appropriate increase of its length so that there are within the tube and away from the diaphragm a node and an antinode. The amplitude at this antinode should be maintained constant while it is under observation in order to insure the constancy of the tube as a source of sound. G. F. S.

Certain Molecular Lengths Measured by an Optical Lever. W. N. BOND. (*Phil. Mag.*, June, 1929.) "The development, construction and use of optical levers is described that enable certain changes in the thickness of a sheet of mica to be measured to an accuracy of 1.5×10^{-8} cm." A piece of hack-saw blade about 1 cm. square formed the body of the lever. To each end of an edge was soldered a steel ball-bearing, 1/32 inch in diameter. The tip of a fine needle was soldered at the middle of the same edge but not quite in line with the spheres. Thus the piece of steel could rest in stable equilibrium in a vertical plane being supported at three places by the points of contact of the two balls and the needle point with some surface below. A small plane mirror was attached to the steel blade by wax. The mass of the optical mirror was only .42 gm. and

its effective length was about .115 mm. The two steel balls rested on the ends of two steel bar magnets. The attraction of the magnets for the balls prevented slipping when the lever was tilted. The needle point rested on the end of a steel screw adjustable in height in order to set the plane of the mirror vertical. Changes in the position of the mirror were detected by setting a spider thread along a central diffraction band formed by light reflected from the mirror. This setting was estimated to 1/1,000 mm. When the lever needed to be tilted a jet of air was directed against it by compressing a rubber bulb some distance away.

The needle point, the central leg of the lever, rested on the end of the steel screw or on a sheet of mica placed on the screw. The lever was tilted until the end of the needle no longer touched its support. Then it was allowed to settle gently back into contact. Ten settings of the microscope were made, the mirror was again tilted and the process was repeated. The mean of each group of ten settings was calculated. These averages will be designated "microscope readings." The difference between consecutive microscope readings was found. When mica was the substance supporting the needle point the variation of the microscope readings was at first ascribed to a lateral shift of the mica, but cementing the mica firmly in place did not eliminate the differences. They persisted even when the point rested on the steel screw. In a series made with mica the differences between consecutive readings expressed in units of 10^{-4} cm. range from .7 to 1006.9. In a series with steel the range is from .7 to 607.5. For both steel and mica the differences of successive microscope readings were analysed to see whether any evidence of periodicity manifested itself. The problem is somewhat like the following. There is a pile of bricks all laid in the same manner. A pointed rod comes down upon the pile. Sometimes it meets the middle of a brick and goes no farther, or it may go into a crack and continue downward for several layers. It is required from the distance the rod descends from a given point to calculate the probable thickness of the bricks as piled.

For mica the thickness of the "brick" or unit cell is computed to be $(10.0 \pm 0.3) \times 10^{-8}$ cm. This agrees well with the value deduced from X-ray experiments, 9.95×10^{-8} cm. For steel the thickness of the unit cell is found to be $(6.8 \pm 0.2) \times 10^{-8}$ cm. which is in agreement with the value of the length of the cementite unit cell deduced by X-ray methods, viz., 6.737×10^{-8} cm. Thus a very interesting confirmation of data derived by a different method is presented. G. F. S.

The Transmission of Sound through Vibrating Partitions. A. H. DAVIS and T. S. LITTLER. (*Phil. Mag.*, June, 1929.) A previous investigation concerned itself with the transmission of sound through materials like felt. In the present paper an examination is made of the passage of sound through partitions that transmit to at least some extent by vibration. Two rooms are separated by a sound-proof wall in which there is an aperture 4 ft. by 5 ft. This size made it certain that the fundamental frequency of the piece of test material covering the opening would be much below that of the sounds used.

In one room a beam of sound was let fall obliquely on the test panel at the aperture and in the other room measurements of the intensity of the transmitted sound were made at different points along the beam. In the second room similar measurements were made with the panel removed. The ratio of transmission was obtained from a comparison of the two sets of measurements. When a source of sound is in continuous operation in a room stationary waves are set up, the waves falling on any surface are partly direct and partly reflected and the source itself may be reacted upon to no small extent. "Owing to reaction upon the source when the incident beam was normal to the test partition, the apparent transmission through felt at 500 cycles per sec. was markedly increased (from 50 per cent. to 300 per cent.) by altering the distance of the source from the partition by one quarter of the wave-length of the sound. "The obliquity of the beam in the source room avoided reaction on the source and the presence of abundant lagging on the walls of both rooms reduced the importance of waves outside the main beam."

The reasonable supposition that a board partition would vibrate under the impact of a sound wave was verified by touching the board with the fingers as well as by more elaborate methods. Thus the transmission of sound through such a vibrating board is not a case of real acoustical refraction. It might thus well be that, owing to the vibration of the partition as a whole, much sound energy is emitted perpendicular to its plane. It was, however, found both by ear and by microphone tests that there was a definite beam in the receiving room and that outside of this beam intensities were rather small. Moreover the beam traverses the partition with little change of form.

To measure the intensity of sound in the receiving room a microphone with amplifier and crystal detector was used. This was swung to and fro along the beam, thus averaging effects over a distance and making it unnecessary to take readings at so many points. The "transmission ratio" is the "ratio between the quantities of sound energy transmitted through the test partition and through the uncovered aperture when the partition is removed."

The results of experiments with paper, sailcloth, felt, fibre board, mahogany and brick work are given. In general the transmission ratio grows less as the frequency of the test sound rises from 300 to 1600 cycles per sec. Cartridge paper transmitted .5 of the incident energy while only a few millionths of the energy emerged from a brick wall built into the aperture or from fibre boards with a wide air space between them. "On the whole, the single-brick wall is superior to the other constructions tested."

Since apartment houses have become so common with their problems of sound insulation, investigations such as the above should prove of value for purposes of design.

G. F. S.

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